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Centre for Alternative Fuel Utilization

COMPLETION OF PRE-TRIAL PHASE OF DIESEL EMISSIONS REDUCTION OPTION DEVELOPMENT

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1. SUMMARY

Initial evaluation has been conducted on the use of heating elements in assisting regeneration of ceramic diesel particulate filters (DPF's). Tests were conducted to determine the particulate concentrations and mutagenicity of the material emitted during forced regneration with an electric heating element.

A heating element rated at 24 volts D.C., 4200 watts was used for the regeneration tests. It was found that artificial regeneration was possible using the heating element in conjunction with a low air stream flow passing over the heater surface.

The heating element was found to effectively regenerate the ceramic filter.

Internal filter temperature data will be assessed by Corning Glass Works (CGW) to determine if regeneration using the faceheater leads to excessive thermal stresses.

The long (≃50 min) regeneration time may be unacceptable from a practical mining operation standpoint. Further efforts should be spent to assess the effectiveness of the faceheater in combination with organo-metallic fuel additives.

ORI

2. INTRODUCTION

Ceramic diesel particulate filters (DPF's) are effective in controlling diesel particulate emissions (typically 85% to 95%). This control efficiency is attractive in light of the continuing efforts to minimize diesel engine emissions in underground mining operations. Previous studies have shown that, in some cases, these filters will automatically regenerate depending on the average exhaust gas temperatures. Fuel additives have been shown to reduce the particulate ignition temperature and thus allows for auto-regeneration of DPF's over lower load factor duty cycles. Catalyzed DPF's also exhibit reduced particulate ignition temperatures. Test results show that diesel powered machines with an average exhaust temperature of >390^{o}C can auto regenerate with either of these two assisted regeneration methods.

Many mining machines have a low load factor and thus have average exhaust gas temperatures well below 390^{o}C. It is evident that other means of promoting DPF regeneration are necessary to improve the overall acceptability of these filters in underground mining operations. Factors which impact the overall acceptability of assisted regeneration methods include:

- should be 'on-board';
- regeneration duration should be short;
- system should be simple and fit neatly into the confines of the mining machine;
- energy requirement should be minimal;
- overall cost (capital and operating) should not be excessive.

This report summarizes the activities and test results of a program task to assess the effectiveness of an electric faceheater for assisted regeneration of DPF's.

3. TEST EQUIPMENT AND PROCEDURES

Ontario Research Foundation was supplied, through CANMET, with Corning ceramic diesel particulate filters (DPF's) from Exhaust Controls of Union, New Jersey. One DPF was mounted with a heating element rated at 24 volts D.C., 4200 watts and supplied by Teledyne Stillman. The element was placed ¼" to ½" from the inlet DPF filter face. Eleven type "K" thermocouples were located at strategic locations within the Corning filter to allow for thermal mapping. Figures 1 and 2 show the location of the thermocouples.

Thermocouples were connected to a Data Translation signal conditioning module with analog to digital conversion using Datametrics A/D convertors. All thermocouple signals were processed using an Apple IIe computer with 128K of memory. A special software program was developed in Assembler and Pascal languages to compute and process the signals. This program scans the thermocouples once every 10 seconds and updates readings when a minimum $\pm 4C^{o}$ temperature change occurs. This feature was implemented to reduce the amount of temperature data storage on disk. If a temperature change of less $\pm 4C^{o}$ occurred then only the time is stored on disk. A separate program was developed to display the temperature profile versus time on a hard copy.

The ceramic DPF was installed on a Deutz F8L-413 F/W diesel engine connected to a Clayton dynamomete. The DPF with thermocouples and heating element was installed on the left exhaust bank of the engine (as viewed from the flywheel end of the engine).

The engine was operated at 2200 RPM with an effective load of 55 HP for DPF build-up. Build-up of the DPF was determined by measuring the differential exhaust backpressures across the DPF. A differential pressure of 51 cm of water was required before burn-off tests could be conducted. The maximum allowable exhaust backpressure for this engine is 100 cm of water. Build-up time for the DPF varied from 11.7 hrs to 14.5 hrs.

Engine temperatures were monitored and recorded during the build-up period using "K" type thermocouples in conjunction with a Doric trendicator and a multipoint selector.

Upon completion of the DPF build-up the ceramic filter was removed from the engine to allow for total emissions sampling during regeneration. The DPF was fitted with appropriate flanges to adapt it into the collection system (see Figure 3). Once mounted into the sampling system, two twelve volt batteries and an ammeter were connected in series with the heating element. Burn-off tests were conducted over a period of 43 to 50 minutes. This was determined by the length of time that the battery was able to retain its charge. The voltage across the batteries and heater element current draw were measured and recorded during all tests.

To increase the thermal conductivity and allow for increased regeneration a low flow rate of ambient air was introduced to the closed end of the filter housing the filter element. This was accomplished by directing and measuring 5 cfm air flow through two temperature compensated dry gas meters set in parallel to each other (as shown in Figure 3).

The exhaust of the DPF was directed through a stainless steel dilution tube that utilized a high volume sampling pump. The sampling system was modified with the addition of a second sampling pump when the need for a higher dilution ratio was observed.

Particulates were collected on a 8" x 10" teflon coated glass fibre filter (type T60A20) followed by two polyurethane foam plugs (PUF's). Before testing, the PUF's were extracted for three separate 8 hour periods. The first extraction required dichloromethane to remove the binding material in the foam. Second and third extractions were performed with cyclohexane to remove interfering contaminants.

3.1 Ames Salmonella Mutagencity Assay

The Particulates collected on the Hi-Vol filters and PUF's were tested for mutagenicity using the Ames Salmonella mutagencity assay. Salmonella tester strain TA-98, in the absence of metabolic activation, was used for the assay. Hi-Vol filters and PUF's were extracted for 16 hours with dichloromethane (DCM). The solvent was then taken to dryness and the weight of the soluble organic fraction (SOF) determined. Samples were then dissolved in dimethyl sulfide (DMSO) at a concentration of 200 µg/mL and submitted for testing in the Ames Salmonella mutagenicity assay. Testing was carried out between 0 and 2000 µg per plate to obtain dose-response data. The specific activity as revertants/µg was then calculated for each of the samples from the linear portion of the dose response curve.

3.2 Gaseous Emissions

Concentrations of total hydrocarbons (THC as CH_4), carbon monoxide (CO), carbon dioxide (CO_2) and oxides of nitrogen (NO_x) were measured and recorded during the burn-off. Raw exhaust concentrations were measured during the first tests, with diluted exhaust concentrations measured for the remaining tests. Emissions were sampled via a heated (190°C) stainless steel sampling line with a portion of the gas being drawn through two heated filters (190°C) and delivered to a THC analyzer (Beckman Model 402). The balance of the sample was directed through a second series of heated filters (190°C) and conditioned by passing it through a Hankinson dryer.

The conditioned sample was delivered, under a controlled flow rate, to a CO analyzer (Beckman Model 867), NO_x analyzer (Beckman Model 951A). A separate sample line directed sample gas through a heat exchanger and water trap before being delivered to a CO_2 analyzer (Beckman Model 864).

4. RESULTS

4.1 Test Particulars and Temperature Observations

Table I summarizes the initial test temperature and peak DPF temperatures detected during the tests. The DPF build-up parameters are shown in Table II. All traps were built up at 2200 RPM and 55 HP.

4.1.1 Burn-off #1

After DPF build-up was completed the filter was allowed to cool to room temperature over a 24 hour period. The DPF was then removed from the engine and mounted into the sampling system. Base DPF temperature was approximately 23°C for the start of this burn-off that lasted for 43 minutes.

With the low base DPF temperature, combustion of particulates was complete directly downstream of the heater element coils. Figure 4 illustrates this clearly. The temperature traces for burn-off #1 (Figures 7 to 12) at the heater end of the trap give the same indication. Thermocouples 1,5 and 6, which are at the centre and edge of the trap (hence not in direct line with the heater elements), show a relatively flat temperature profile, peaking at 350°C to 400°C. Thermocouples 3 and 4 however, directly behind the heater element, have peaks of 600°C and 800°C. Figures 13 to 17 (thermocouples located halfway through the traps as shown in (Figure 1) showed the highest temperature at the centre of the trap

(T_1'), and gradually decreasing temperatures toward the centre edge T_2' and T_3'. This illustrates that hot spots were occurring in different areas of the trap when starting regeneration with a cool base temperature.

4.1.2 Burn-off #2 and #3

For these tests the DPF was wrapped with Kao-wool insulation to reduce heat loss and maintain a higher DPF internal temperature prior to initiating the burn-off. The DPF temperature was increased before testing by operating the engine at 2200 RPM at 125 HP. Exhaust temperature was raised to approximately 390°C at this condition. For test #2 the engine was operated for 5 minutes at this setting and 10 minutes for test #3. For both tests the DPF was mounted in the sampling system and burn-off initiated within 30 minutes of shutting the engine down. Burn-off periods lasted 45 minutes for test #2 and 50 minutes for test #3. The initial DPF temperature ranged from 230°C to 400°C for both tests depending on the location of the thermocouples in the filter.

These two tests showed basically the same temperature profiles with a few exceptions. Figure 5 shows that the higher base temperature provided for a more complete regeneration at the front end of the DPF. The temperature profiles are shown in Figures 18 to 29 for burn #2 and Figures 30 to 41 for burn #3.

With the high base DPF temperature condition the temperature was observed to peak for thermocouples 1 to 4 (front of trap) about 10-20 minutes into the test. All four thermocouples had peaks or plateaus >550°C, therefore thermal stresses should not be as great as with test #1. At the middle of the trap the inner 4 temperatures (T_1' to T_4') are relatively similar with the peaks occurring a little later, suggesting the advance of a combustion front. The outer trap temperatures are not

similar however. Figures 22, 23 and 28 (burn #2) show that a combustion front reached T_5 at ≃20 minutes, T_6 at ≃22 minutes and T_5' at ≃25 minutes into the test. In burn #3 there is evidence that the combustion started at T_1' to T_4' a few minutes later than at the front of the trap. However, as can be seen in Figures 34, 35, 40 and 41, there is no evidence of the combustion front reaching the outer part of the trap.

4.1.3 Burn-off #4

With the DPF still insulated, the DPF was removed immediately after build-up at an engine setting of 2200 RPM at 55 HP. At the time of the engine shut down the temperature of the exhaust gases was recorded at 246°C. The initial DPF temperature, measured before regeneration, ranged from 150°C to 220°C.

The dilution tube temperature was reduced for this burn-off by modifying the sampling system to fit in two high-volume sampling pumps. This increased the dilution air flowrate and dilution ratio during the test.

The burn-off pattern on the filter face was similar to burn #1 with the soot burned off only behind the heater element. However, due to an electrical problem in the measurement system, the thermocouple data was not useable.

4.1.4 Particulate Test Results

Analysis of the Hi-Vol filters and PUF's for the soluble and insoluble fractions of the total particulates collected is summarized in Table III. For the first three tests, solubles made up 30.1% to 37.7% of the total particulates. It was found that 78% and 81% of the solubles were collected on the PUF's with 77% and 79% insolubles collected on the 8" x

10" collection filter for tests 2 and 3. The high pass-through of solubles may be attributable to the high dilution tube temperatures.

The solubles collected during the fourth test accounted for 23% of the total particulates. A reduction of pass-through solubles was found with 61% of the solubles collected on the PUF's. Reduction of pass-through solubles is probably due to lower dilution tube temperatures. A general increase in total particulates can be observed, with the lower initial DPF temperature (Tests 1 and 4) being a possible reason.

During burn #1 PUF's were not utilized in the sampling systems, therefore, the total amount of particulates was not determined. Lower particulate collection on the 8" x 10" filter during Test #1 may also be attributed to the higher dilution tube temperature, suspected pass-through of particulates, and incomplete regeneration as shown in Figure 4.

4.1.5 Gaseous Emissions Summary

From raw emissions data summarized in Figures 42 to 49 and Appendix Figures 1 to 8, it can be observed that the emission peaks occur approximately at the same time as the temperature peaks. There were no observable trends between tests. Carbon dioxide peaks ranged from 2 to 7% when corrected back to undiluted concentrations. Carbon monoxide peaks went off scale in the 1 to 2% range except for test #4 which was measured at 1.4%. Total hydrocarbon peaks ranged from 60 to 280 ppm and the nitrogen oxides ranged from 60 to 140 ppm.

4.1.6 Ames Mutagenic Assay Results

Ames Salmonella mutagenicity assay results are summarized in Table IV. A negative mutagenic response was determined for the particulate fraction collected on the PUF's. An average specific mutagenic activity of 1.37

revertants per microgram of soluble particulate was found on the Hi-Vol filter. This revertant concentration resulted in an average concentration 1f 1716 revertants per cubic metre of gas passed through the DPF's. Test #4 had the lowest revertant concentration (0.49) compared to 1.0 and 2.62 for tests 2 and 3 respectively. This may be due to test #4 having a lower percentage of soluble particulates and starting the burn-off at a lower base temperature.

4.1.7 Voltage and Amperage Summary

Two, twelve volt batteries, connected in series, were utilized as the power source for the heating element. The initial voltage was recorded as 22.8 volts for each test with a current reading of approximately 160 amps. The discharge of the battery was reflected by the gradual decrease of both readings over a period of 35 to 40 minutes as shown in Figure 50. After this time period, the voltage and amperage dropped off quickly. The batteries were recharged before each test.

5. CONCLUSIONS

The heating element proved to be effective in regenerating loaded ceramic traps when the traps were purged flushed with 5 cfm of air.

Starting regeneration with a cool trap (23^{o}C) resulted inhot spots in the traps. When a presoaked hot trap (230^{o}C to 400^{o}C) was regenerated the regeneration was more complete and resulted in reduced high temperature zones.

Regeneration time was approximately 50 minutes based, on a 22.8 VDC at 170 amperes starting condition.

Carbon dioxide, total hydrocarbons and total oxides of nitrogen levels were at lower concentrations, or as low as, normally found in the raw exhaust of the Deutz F8L-413 F/W. Carbon monoxide concentration was found to be 1.4% or higher and is approximately 100 times higher than normal diesel exhaust. Total particulate ranged from 9 to 57 mg/m^3 and is less than the raw engine exhaust concentration. However, the 5 cfm flow rate here is considerably less than the maximum 400 cfm exhaust flow rate of the test engine.

Ames mutagenic activity in raw engine exhaust is approximately ≃14,000 revertants per cubic metre while during the regeneration they were only ≃1,700 revertants per cubic metre; again with a much lower flow rate.

The electric face heater is effective for regeneration of DPF's without causing any significant emissions provided it is performed in a well ventilated area.

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Engineering Sciences Division

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TABLE I

TEMPERATURE SUMMARY

Burn-off Test No.	Exhaust Gas Temp. Before DPF Removed from Engine (^{o}C)	Initial DPF Internal Temp. for Burn-off (^{o}C)	Max. Temp. of DPF During Burn-off (^{o}C)
1	23	23	>1000
2	390	230-400	~ 900
3	390	230-400	~ 930
4	246	150-250	~ 950

ERRATUM

Contents (Table II: DPF Build-up Parameters of Engine Assembly at 2200 RPM/55 HP)

The following is an explanation of thermocouple locations for temperatures found in Table II. (Locations referenced from flywheel end.)

T1 - intake combustion air

T2 - right exhaust - no DPF

T3 - left wheel - before DPF

T4 - fuel temperature

T5 - cylinder head temperature

T6 - oil temperature

T7 - cooling air intake

T8 - left exhaust - after DPF

TABLE II

DPF BUILD-UP PARAMETERS OF ENGINE ASSEMBLY AT 2200 RPM/55 HP

Test #	Time hrs.	Backpressure (CmH_2O) Before DPF	After DPF	DP	Temperatures ^oC (Locations Reference to Figure) T1	T2	T3	T4	T5	T6	T7	T8
1	0	25	9.5		20	350	375	19	109	101	19	359
	12.75	59	8	51	21	243	247	20	89	92	20	231
2	0	27	8.5		21	240	237	20	88	92	19	230
	12.75	58.5	7.5	51.5	24	254	249	24	91	93	23	247
3	0	11	7.5		22	232	226	18	80	75	20	198
	**14.75	59.5	8.0	51.5	20	236	238	18	83	91	18	235
4	0	17	8.5		24	250	246	19	88	79	18	234
	11.75	59.5	9.0	50.5	27	251	251	27	97	94	29	246

* High temperatures due to engine induced burn-off previous to beginning of build-up.

** Longer build-up time attributed to a leak that was corrected during the early build-up hours.

TABLE III

PARTICULATE DATA

Burn-off Test No.	Insoluble Loading (mg)	(mg/m^3)	% of Total	Soluble Loading (mg)	(mg/m^3)	% of Total	Total (mg)	Concentration (mg/m^3)
1 Hi-Vol Filter	124.3	18.19	67.7	59.3	8.68	32.3	183.6	26.86
Pufs	-	-	-	none used -		-	-	-
2 Hi-Vol Filter	51.1		85.4	8.7		14.6	59.8	
Pufs	15.4		32.8	31.6		67.2	47.0	
Combined	66.5	10.05	62.3	40.3	6.09	37.7	106.8	16.14
3 Hi-Vol Filter	38.2		90.7	3.9		9.3	42.1	
Pufs	10.1		37.4	16.9		62.6	27.0	
Combined	48.3	6.23	69.9	20.8	2.681	30.1	69.1	8.916
4 Hi-Vol Filter	273.3		87.3	39.7		12.7	313.0	
Pufs	70.0		53.0	62.0		47.0	132.0	
Combined	343.3	44.42	77.1	101.7	13.16	22.9	445.0	57.58

ERRATUM

Contents (Table III: Particulate Data)

The loading values (mg/m^3) of the insoluble and soluble particulates were calculated using the corrected volume of air passed through the DPF's via dry gas meters.

TABLE IV

AMES ACTIVITY*

Burn-off Test No.		Specific Activity (revertants/μg)	Mutagen Concentration (revertants/m^3)	Soluble Organic Fraction (mg/m^3)
2	Hi-Vol Filter	1.00	1314	1.3
	Pufs	Negative (non-mutagenic)	Neg.	4.77
3	Hi-Vol Filter	2.62	1318	0.5
	Pufs	Neg.	Neg.	2.17
4	Hi-Vol Filter	0.49	2517	5.1
	Pufs	Neg.	Neg.	8.02

* Note mutagen concentration (rev/m^3) based on air volume supplied to the DPFs (0.14 m^3/min). Ames test not conducted on sample from Test 1.

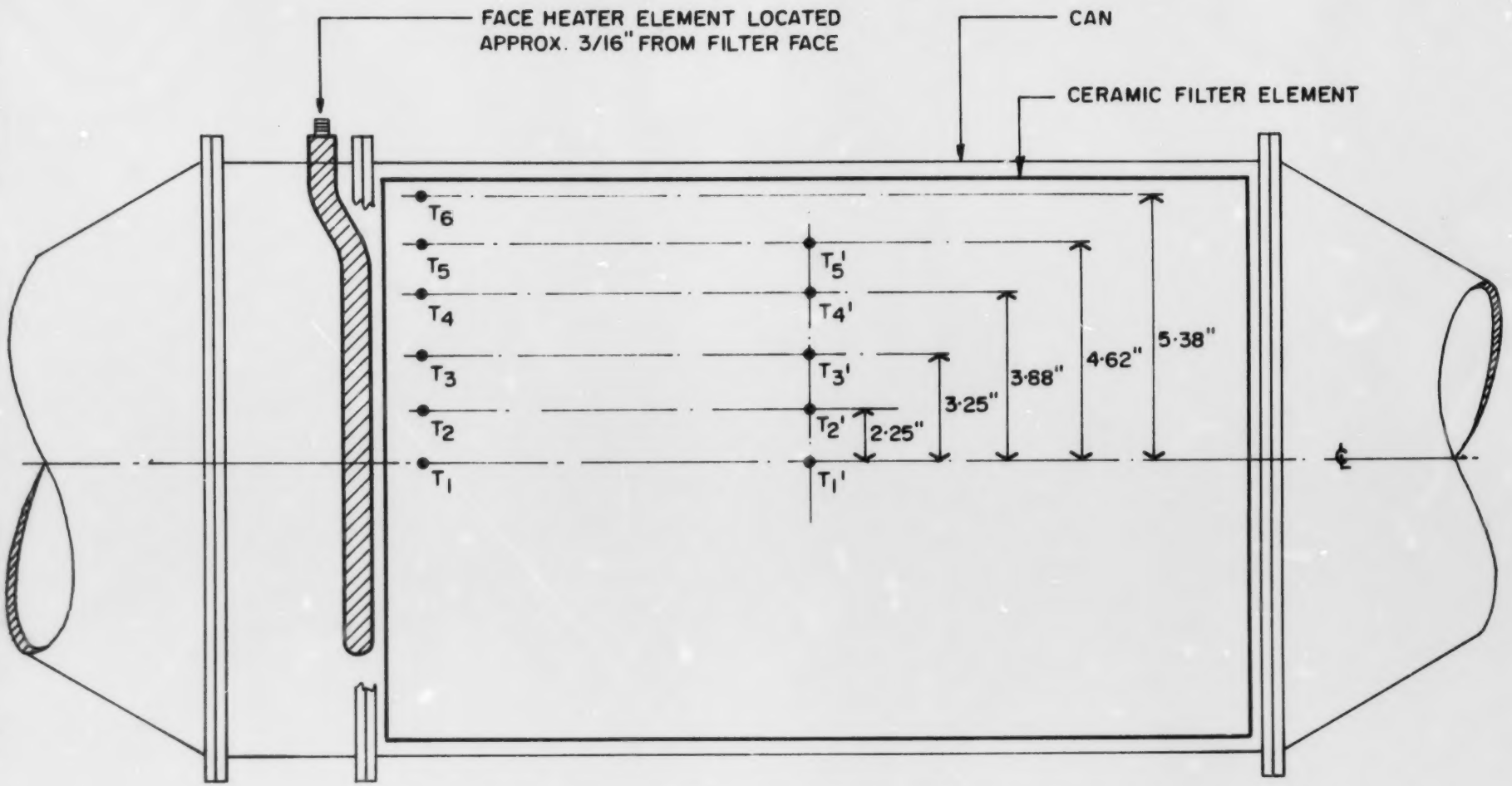

FIGURE 1 SCHEMATIC OF CERAMIC FILTER SHOWING THERMOCOUPLE LOCATIONS

FIGURE 2

View of DPF Outlet Face

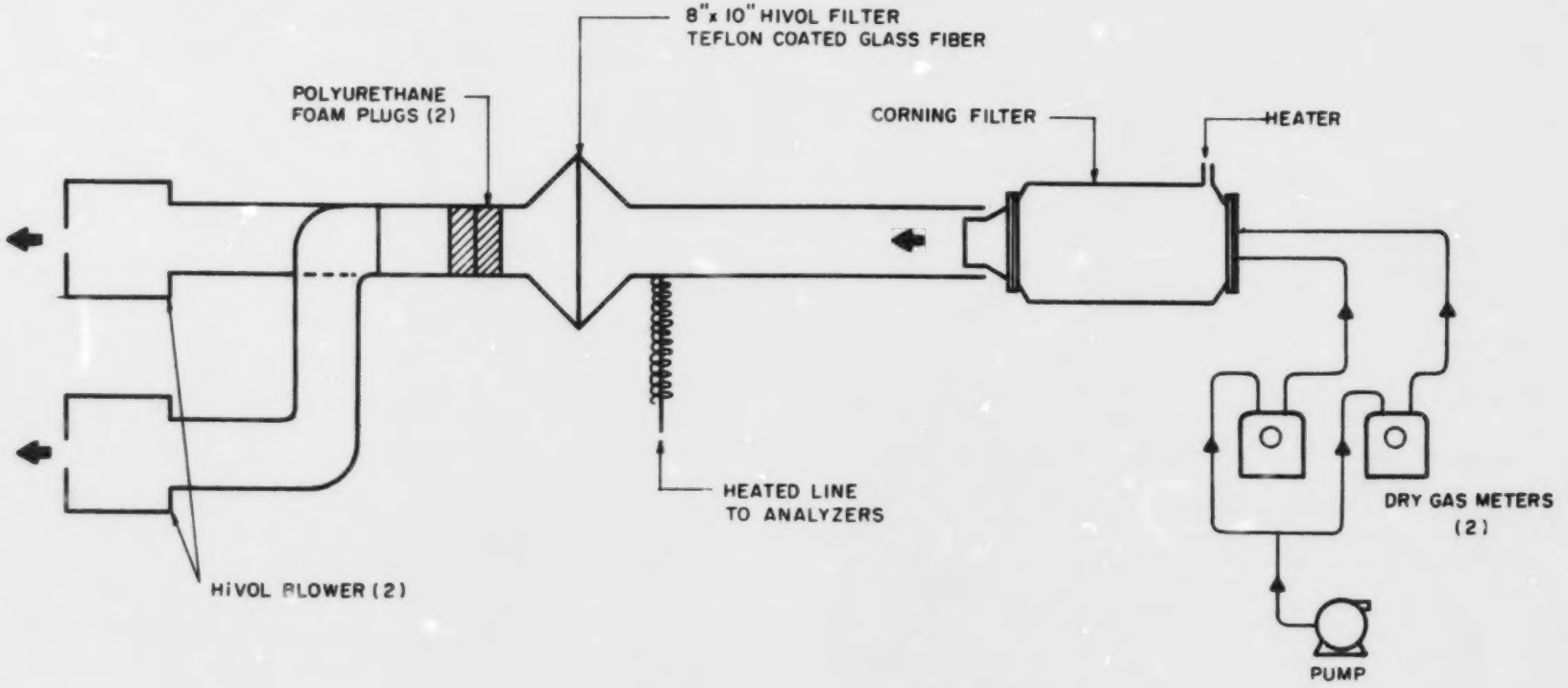

FIGURE 3 MODIFIED DILUTION TUBE SAMPLING SYSTEM SCHEMATIC.

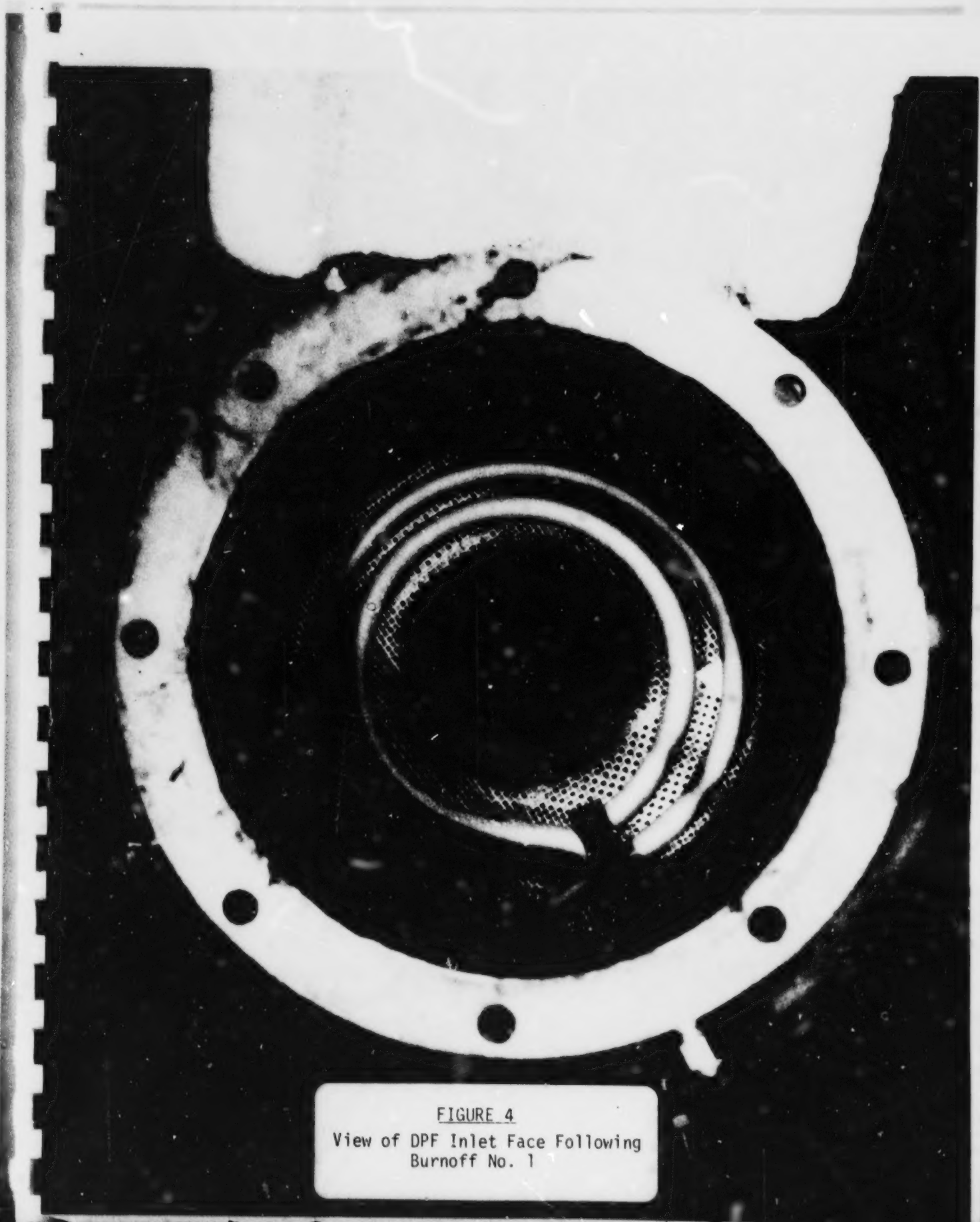

FIGURE 4
View of DPF Inlet Face Following
Burnoff No. 1

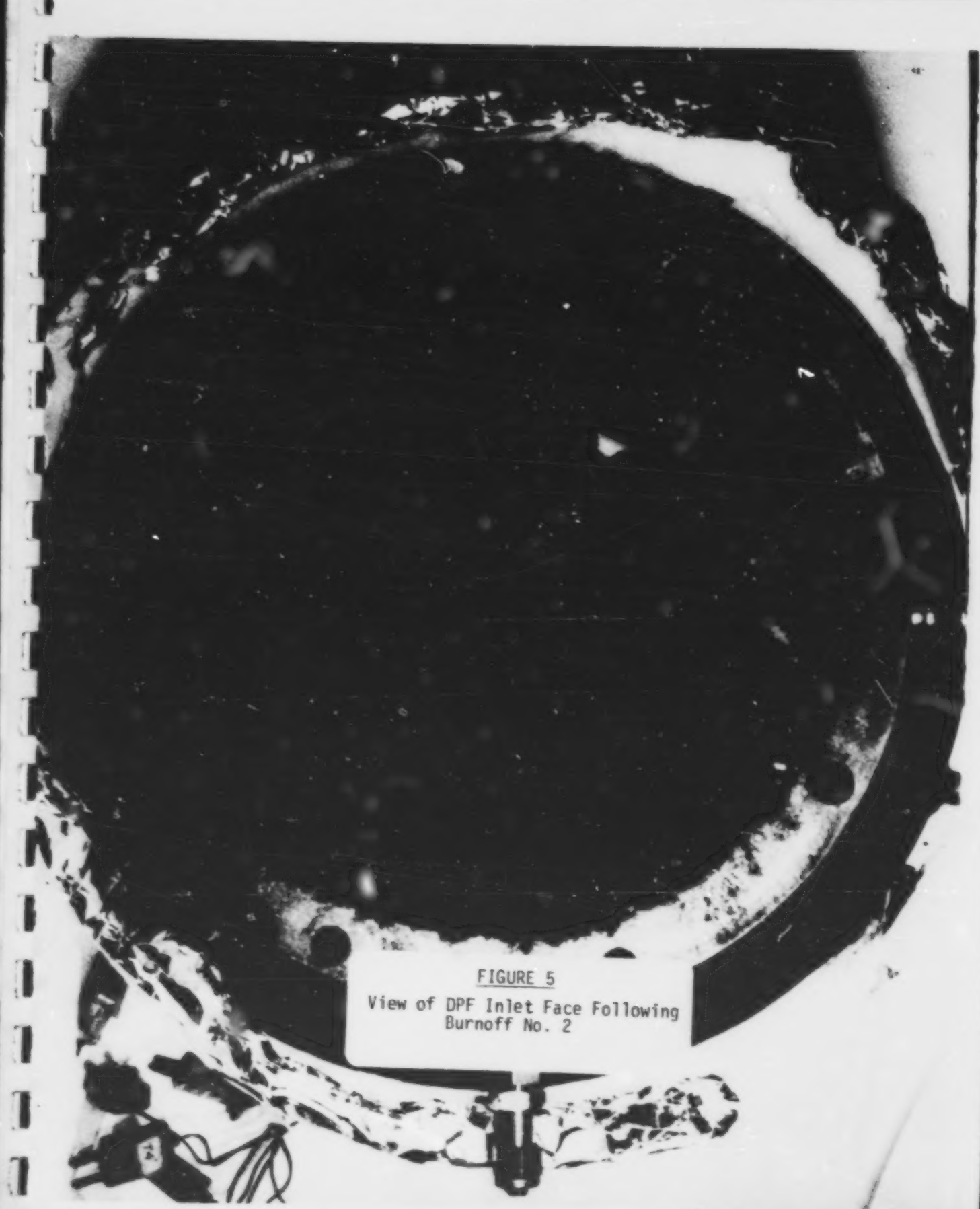

FIGURE 5

View of DPF Inlet Face Following Burnoff No. 2

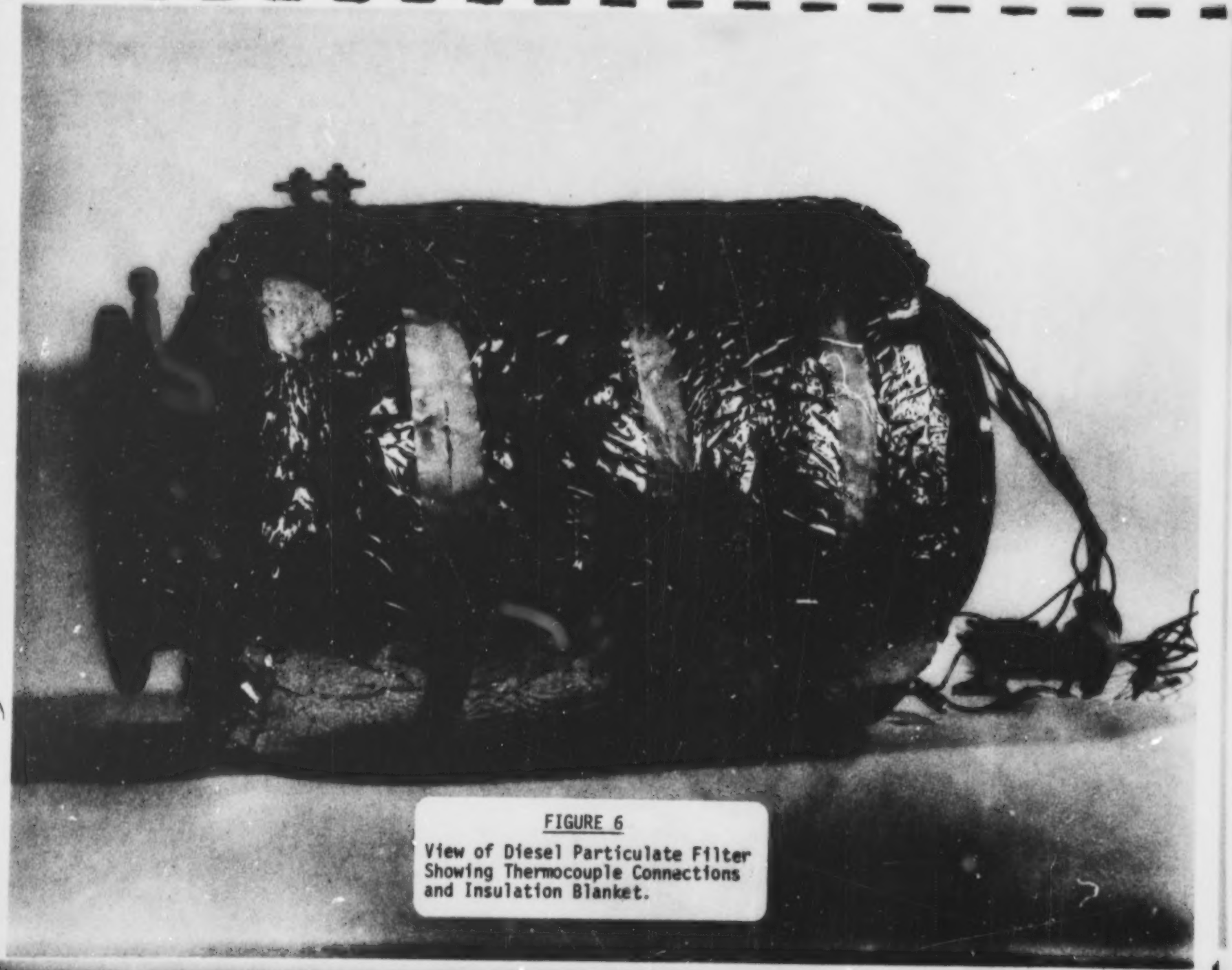

FIGURE 6

View of Diesel Particulate Filter Showing Thermocouple Connections and Insulation Blanket.

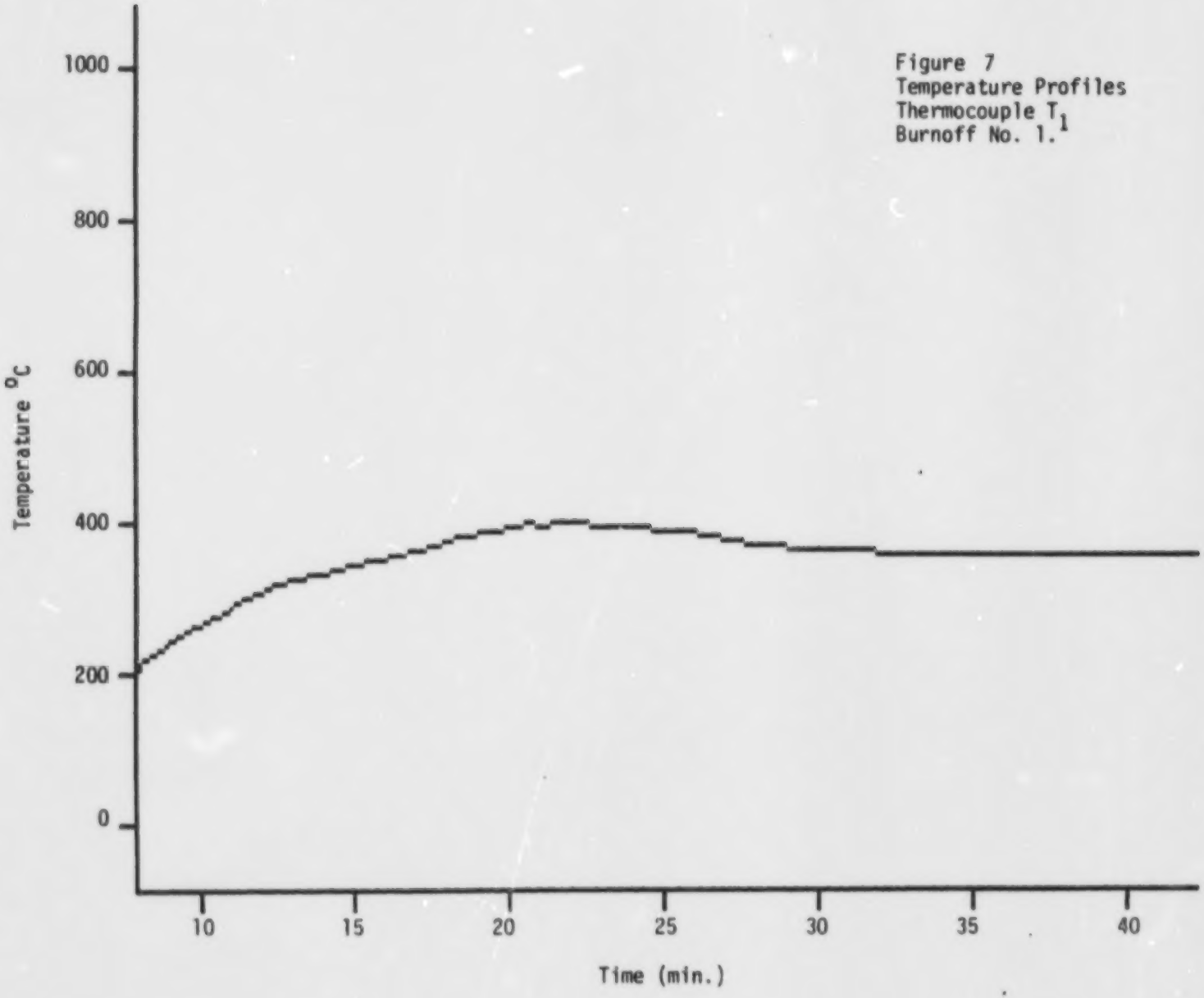

Figure 7
Temperature Profiles
Thermocouple T_1
Burnoff No. 1.

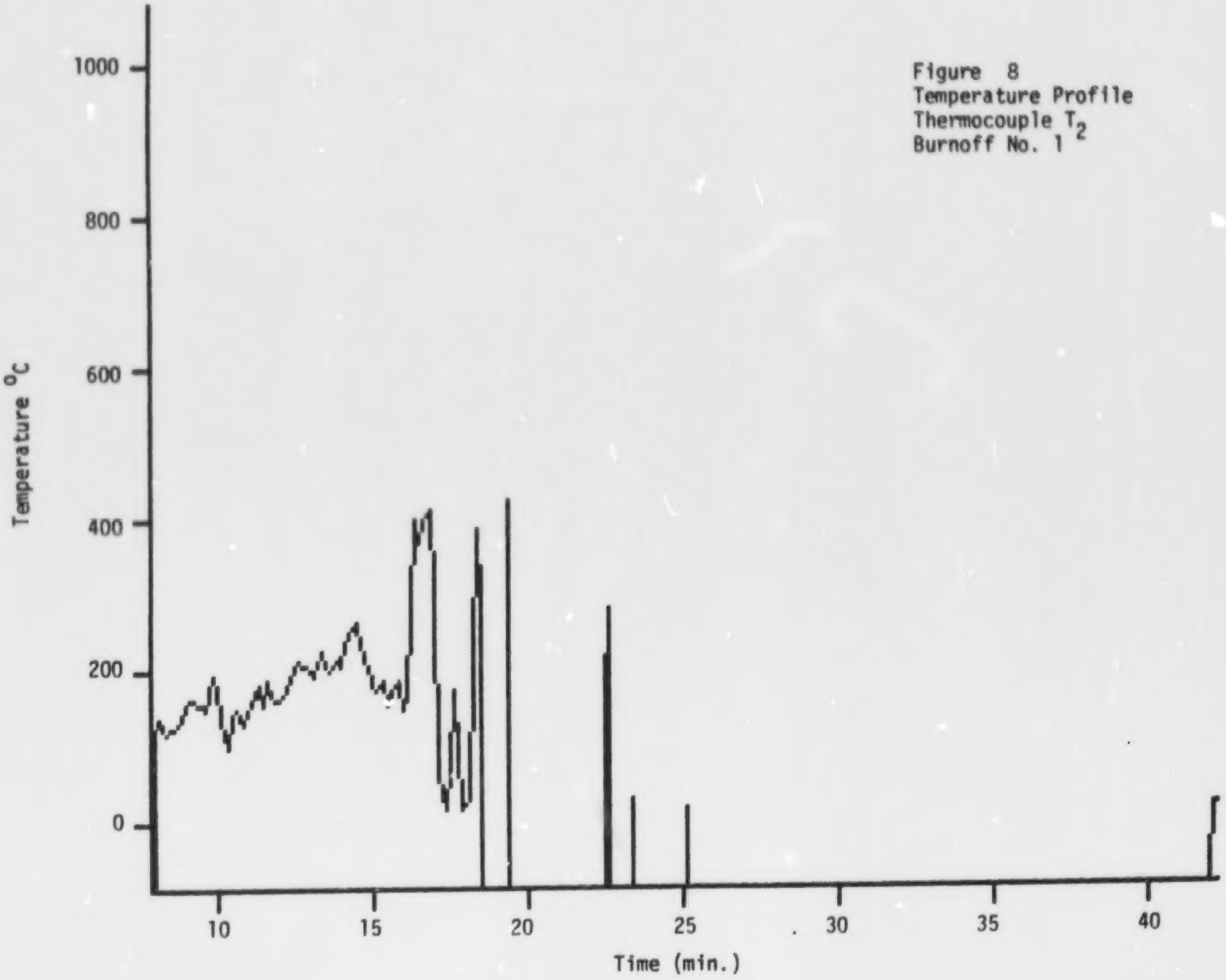

Figure 8
Temperature Profile
Thermocouple T_2
Burnoff No. 1

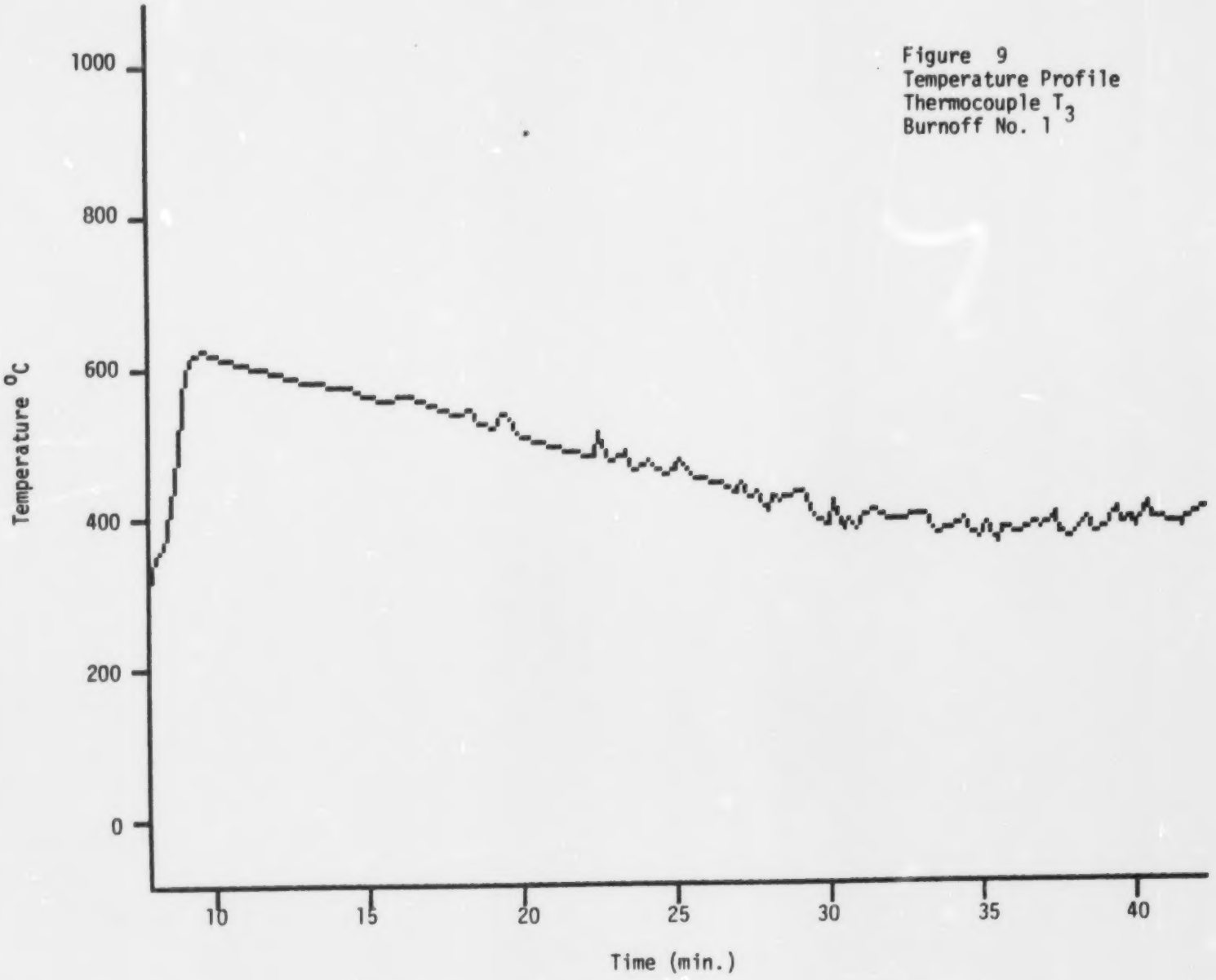

Figure 9
Temperature Profile
Thermocouple T_3
Burnoff No. 1

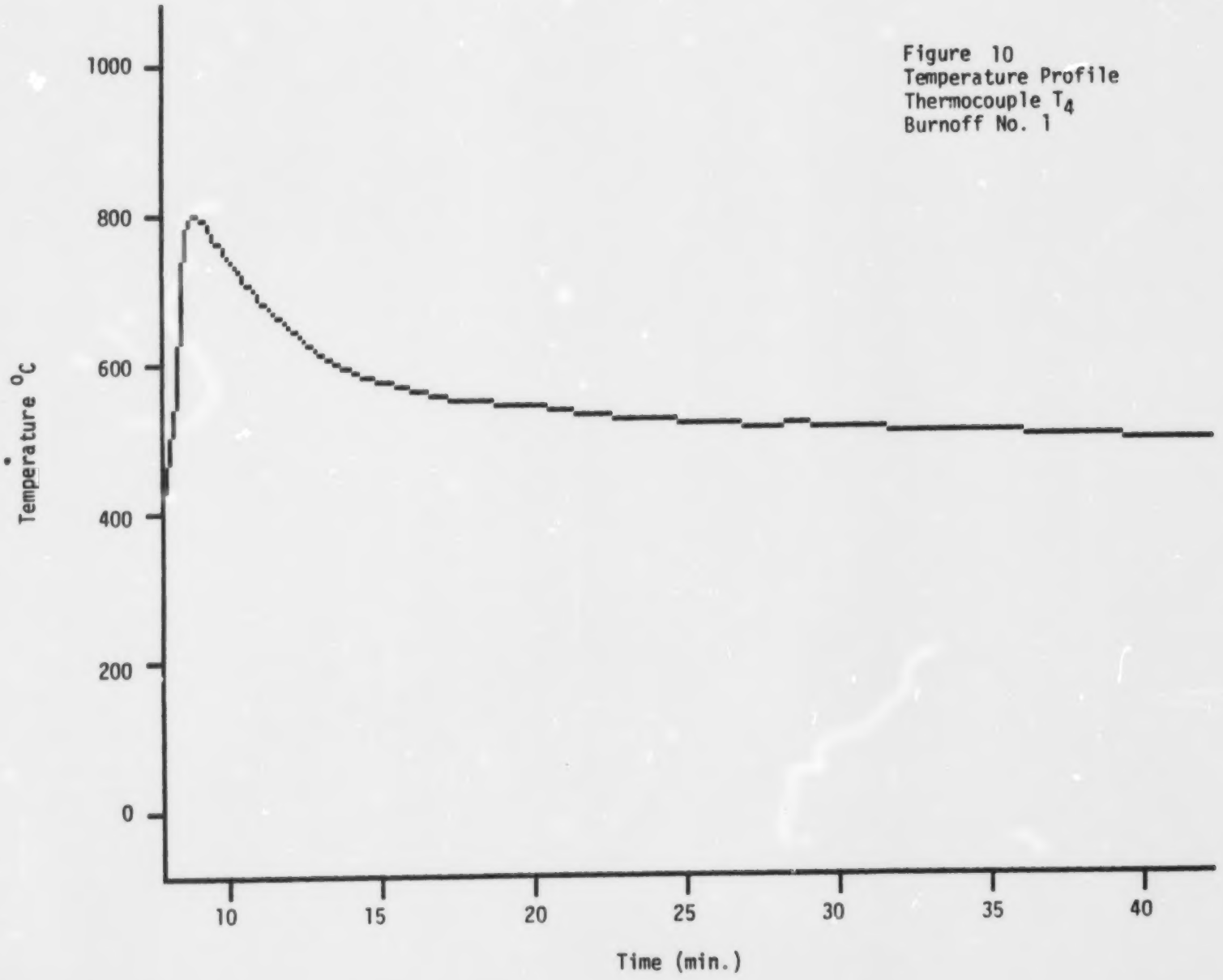

Figure 10
Temperature Profile
Thermocouple T_4
Burnoff No. 1

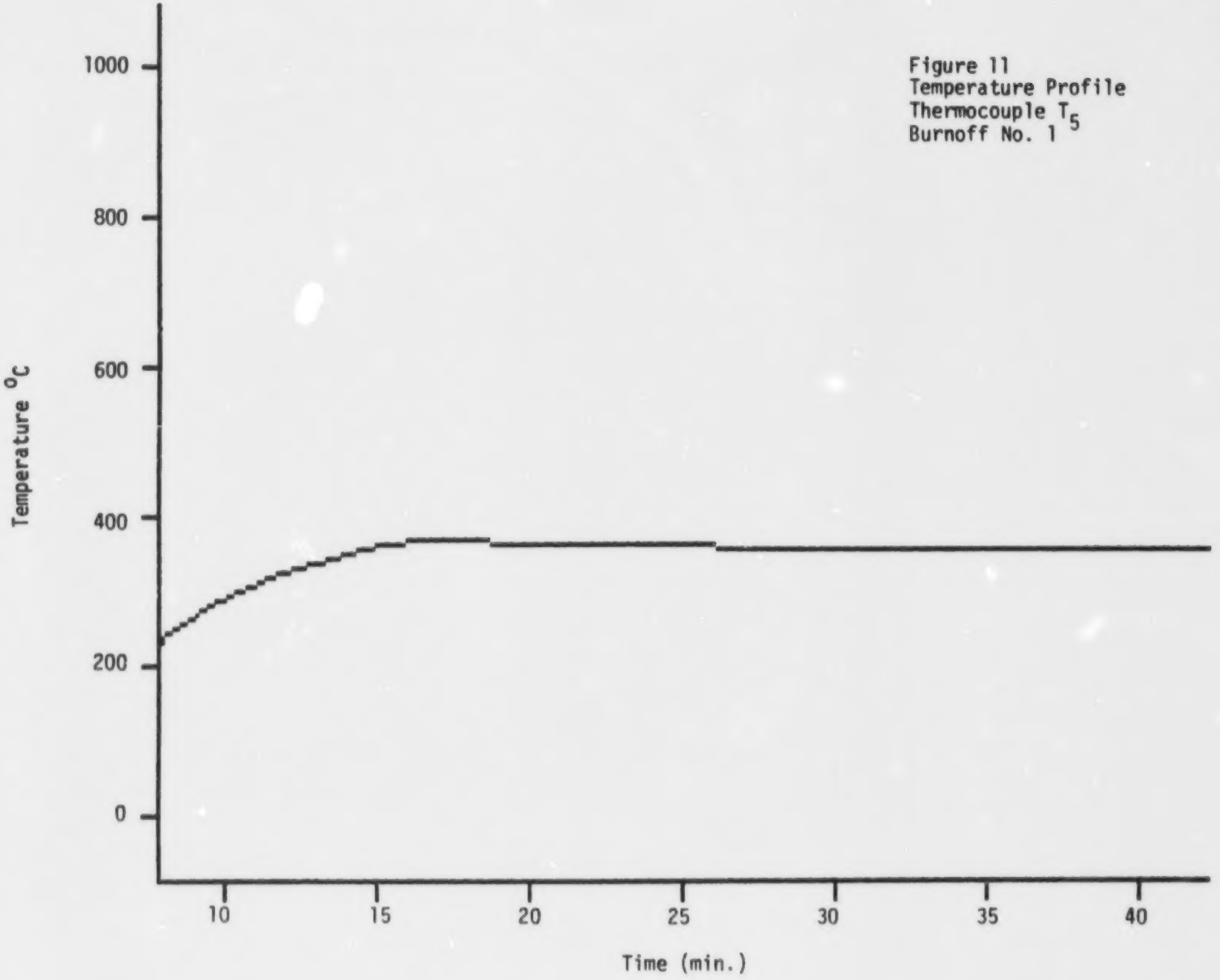

Figure 11
Temperature Profile
Thermocouple T_5
Burnoff No. 1

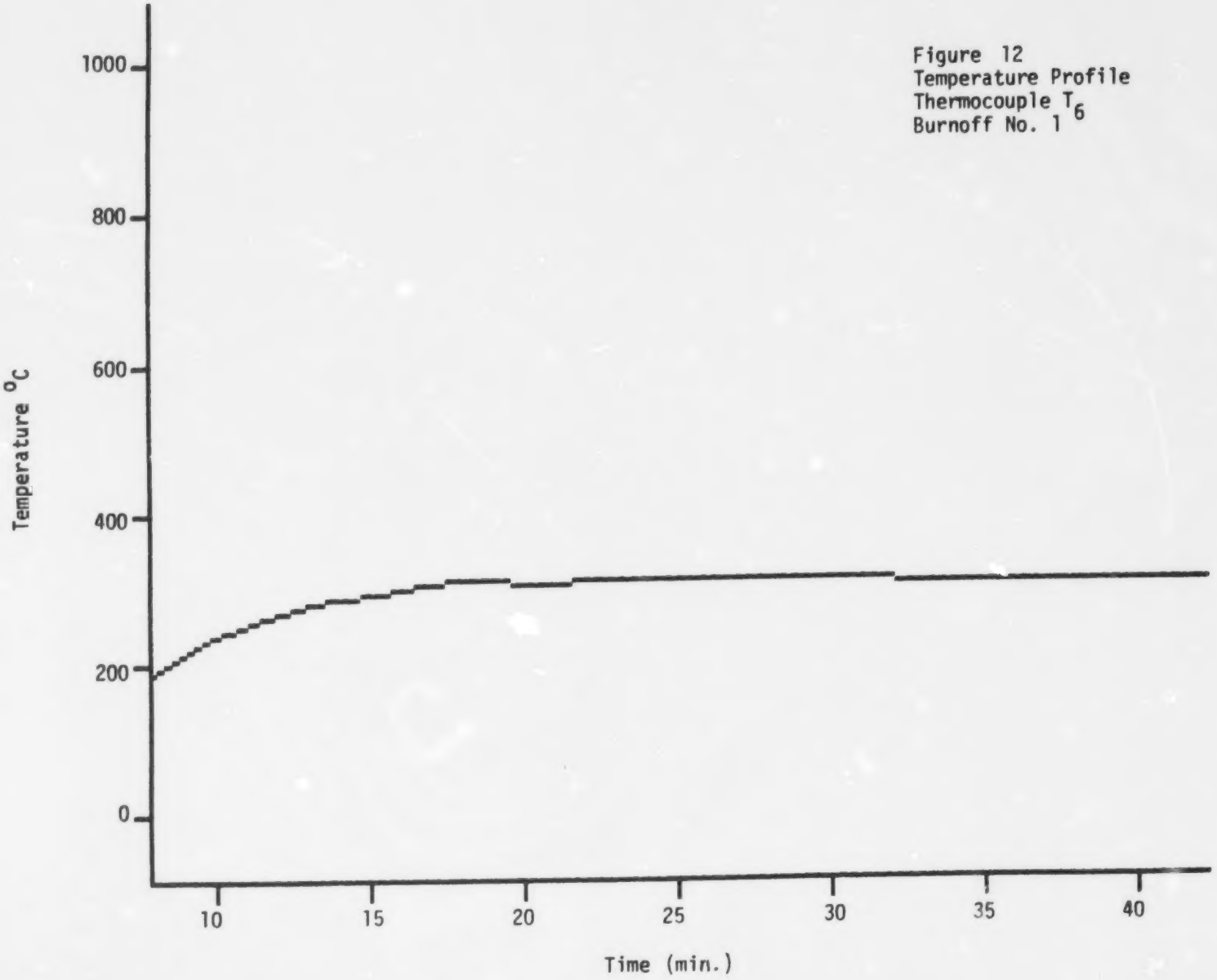

Figure 12
Temperature Profile
Thermocouple T_6
Burnoff No. 1

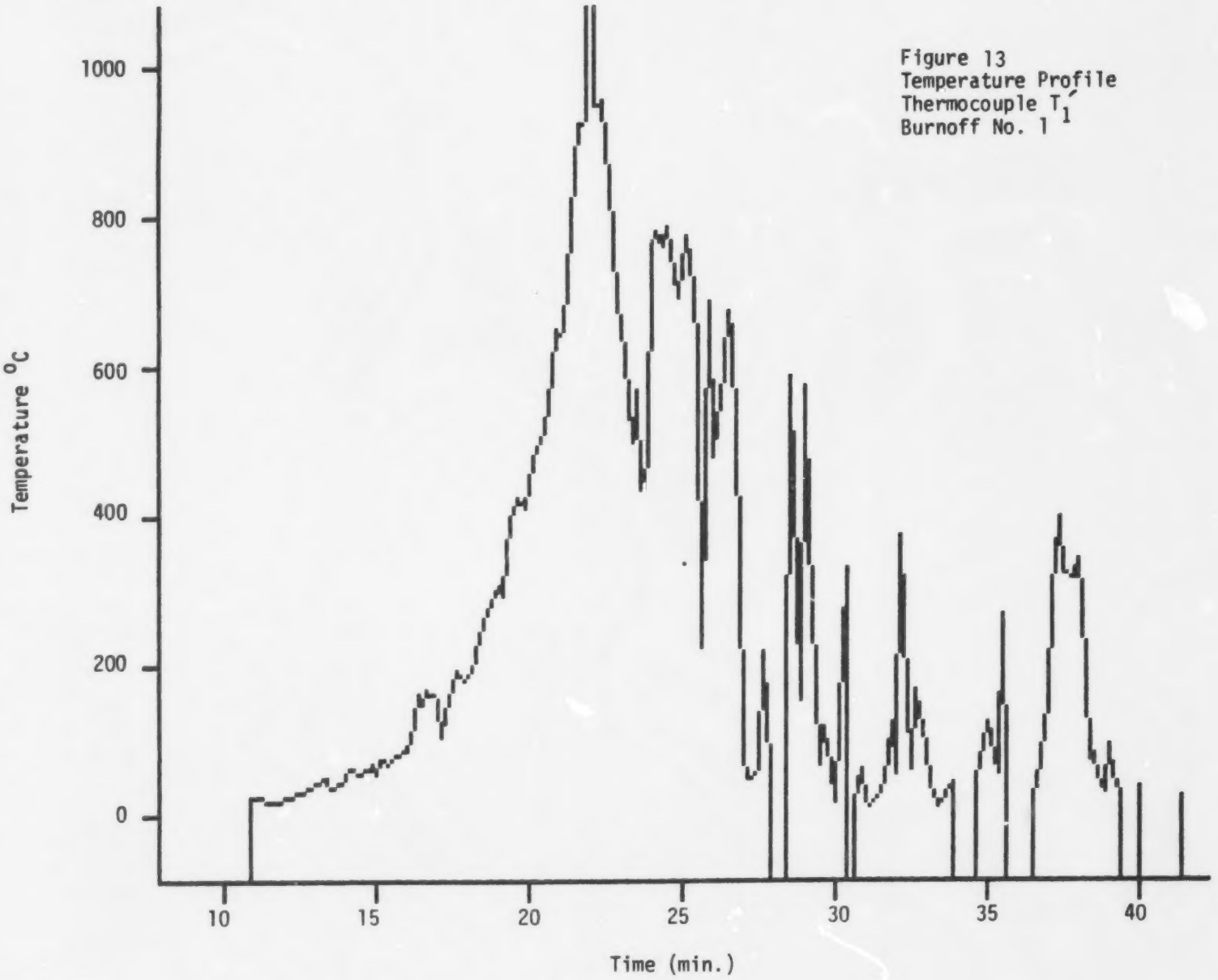

Figure 13
Temperature Profile
Thermocouple T_1'
Burnoff No. 1

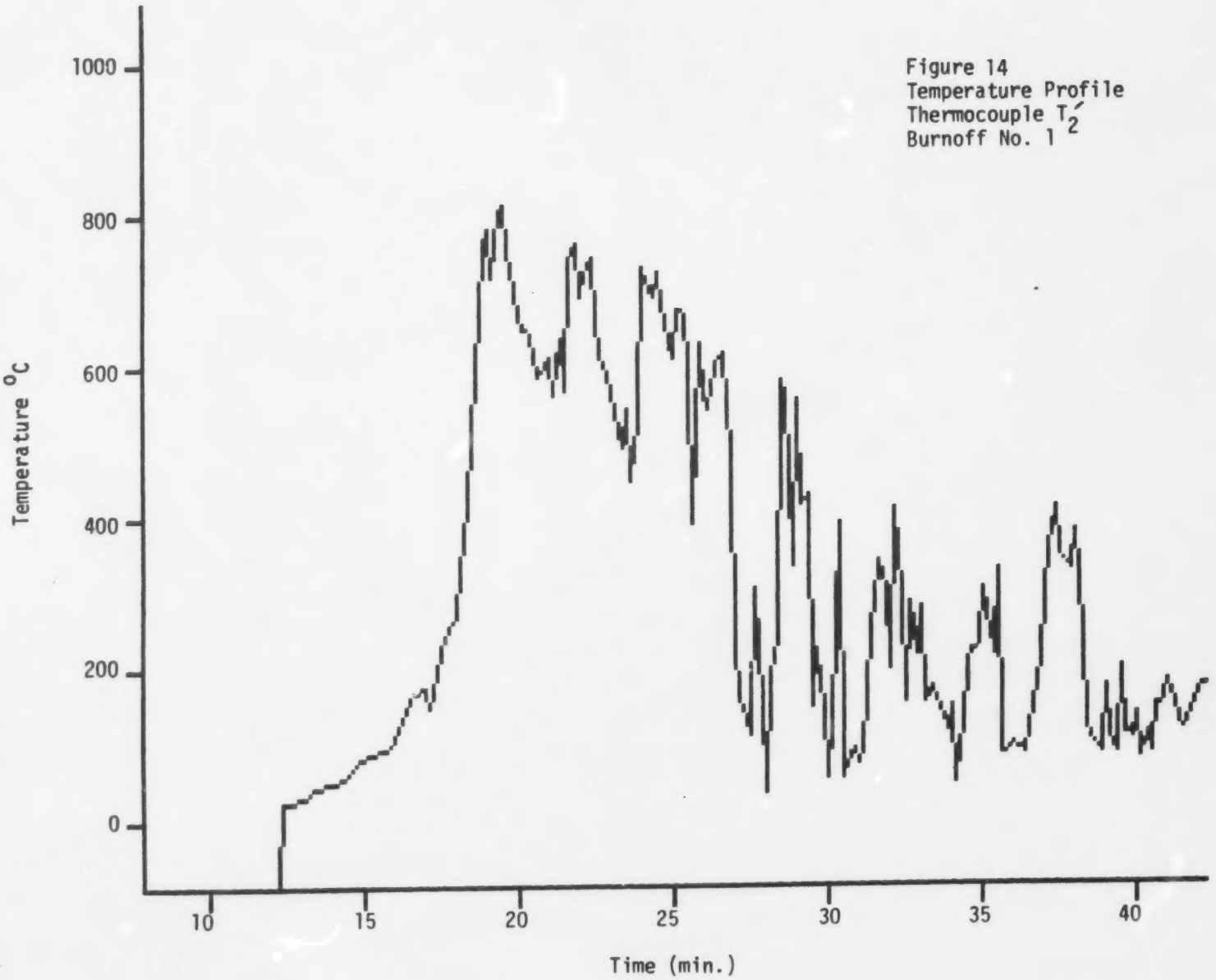

Figure 14
Temperature Profile
Thermocouple T_2'
Burnoff No. 1

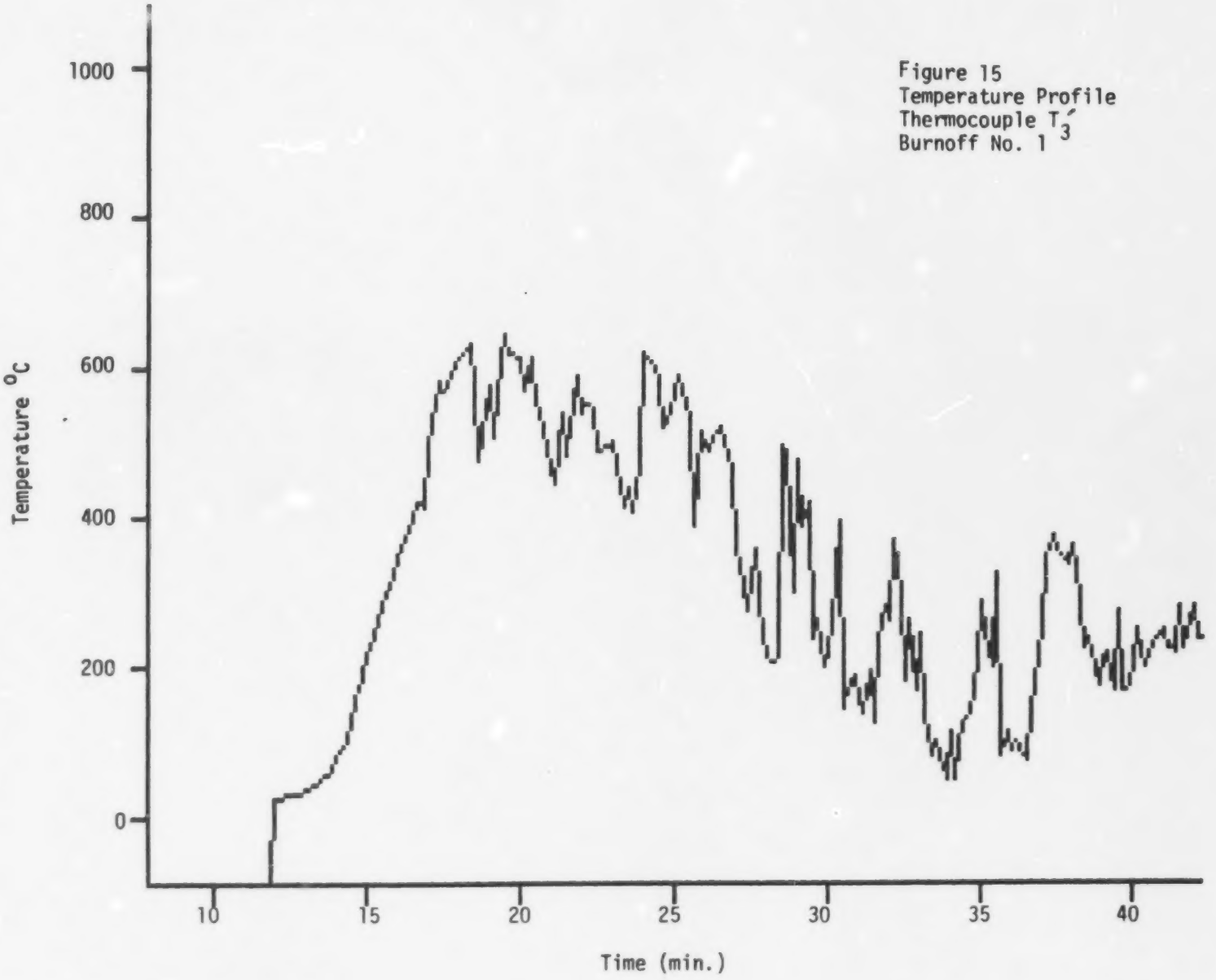

Figure 15
Temperature Profile
Thermocouple T_3'
Burnoff No. 1

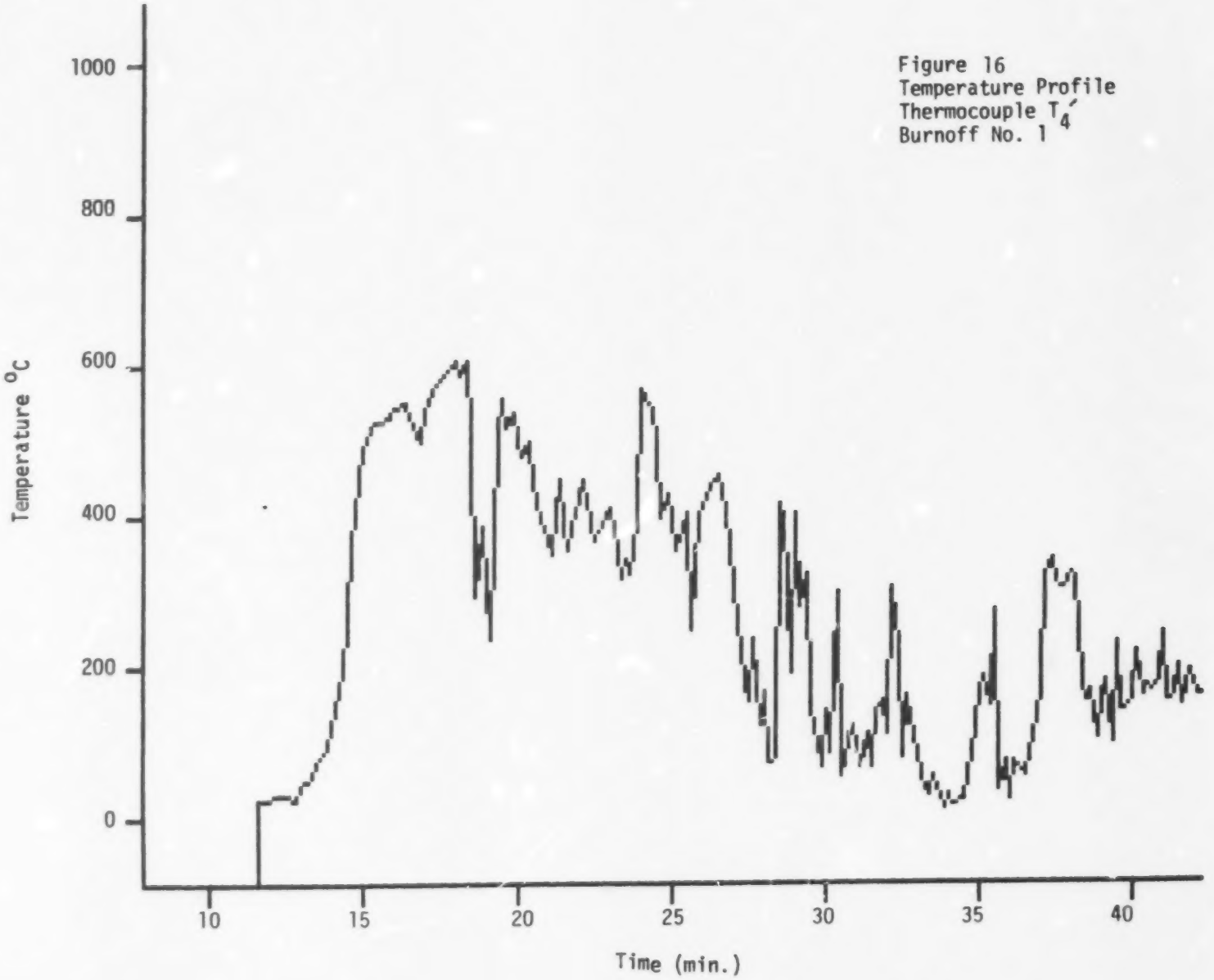

Figure 16
Temperature Profile
Thermocouple T_4'
Burnoff No. 1

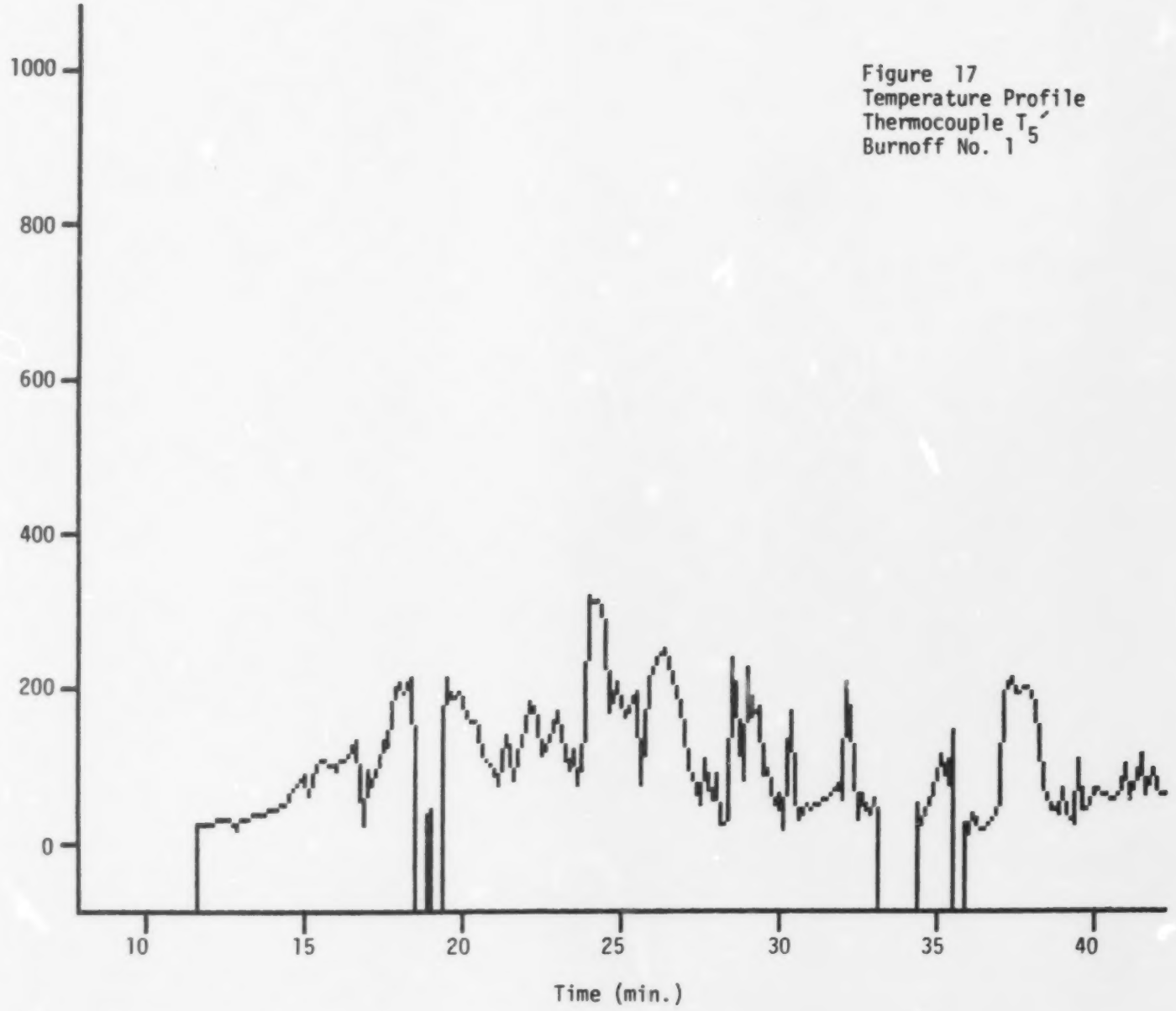

Figure 17
Temperature Profile
Thermocouple T_5'
Burnoff No. 1

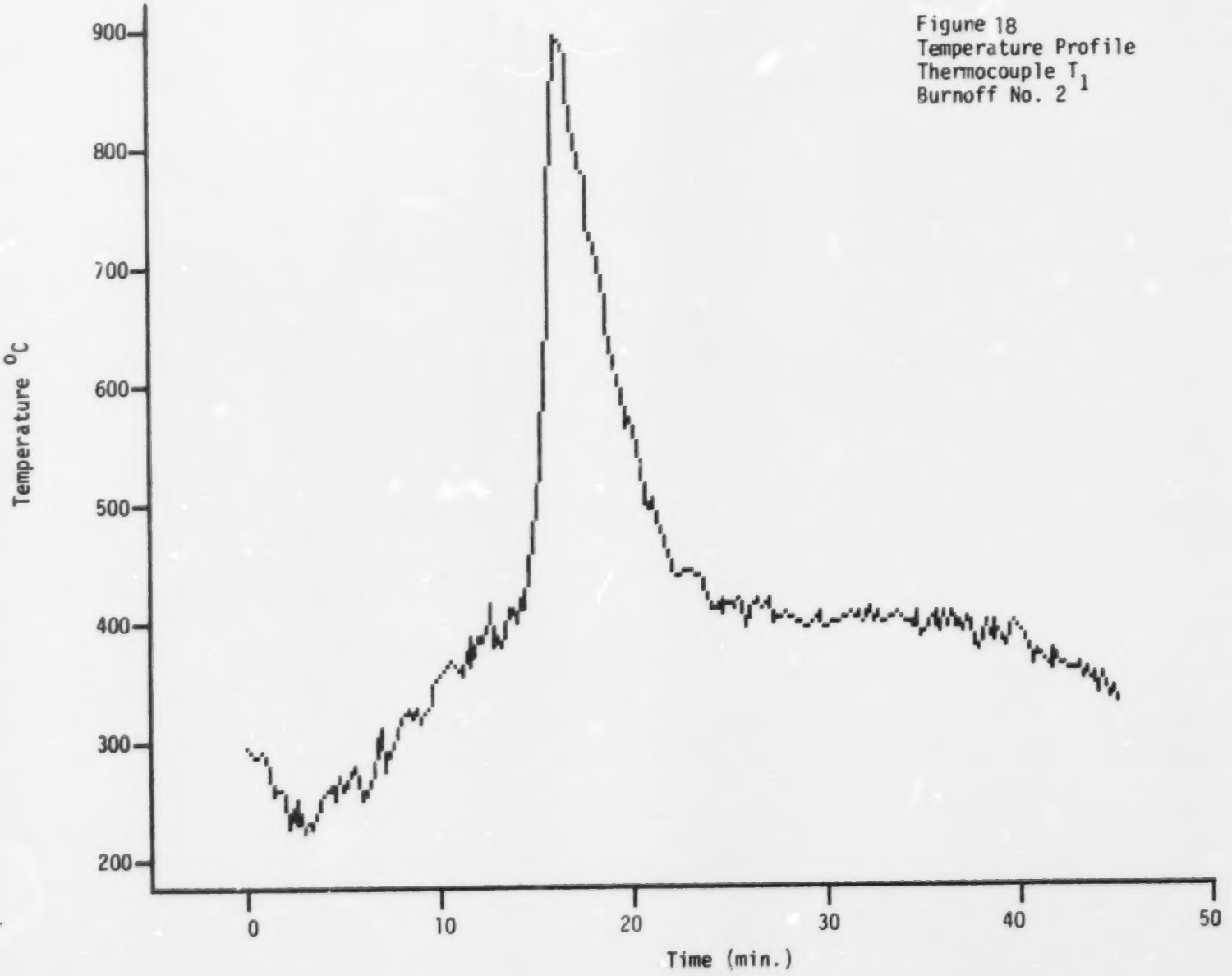

Figure 18
Temperature Profile
Thermocouple T_1
Burnoff No. 2

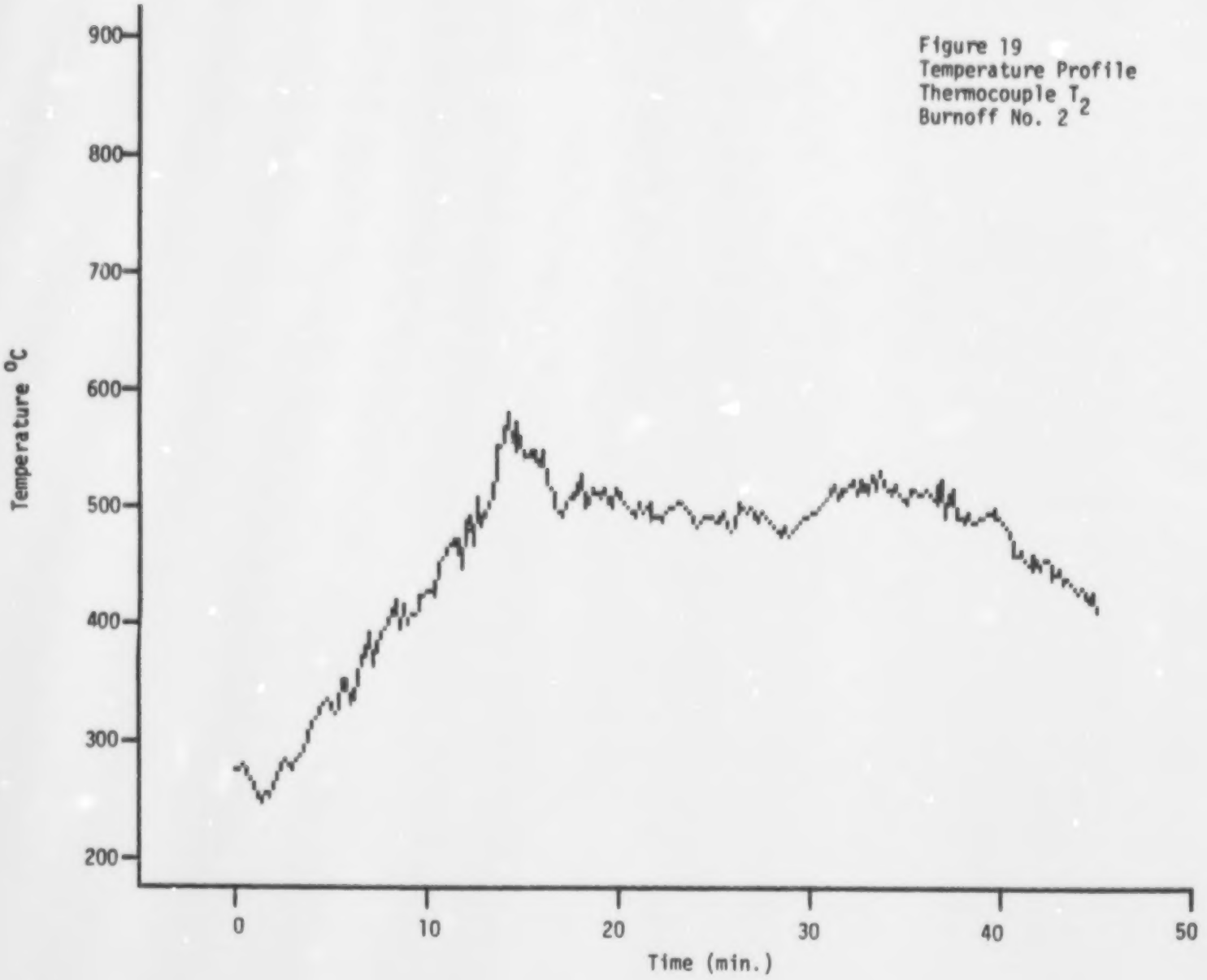

Figure 19
Temperature Profile
Thermocouple T_2
Burnoff No. 2

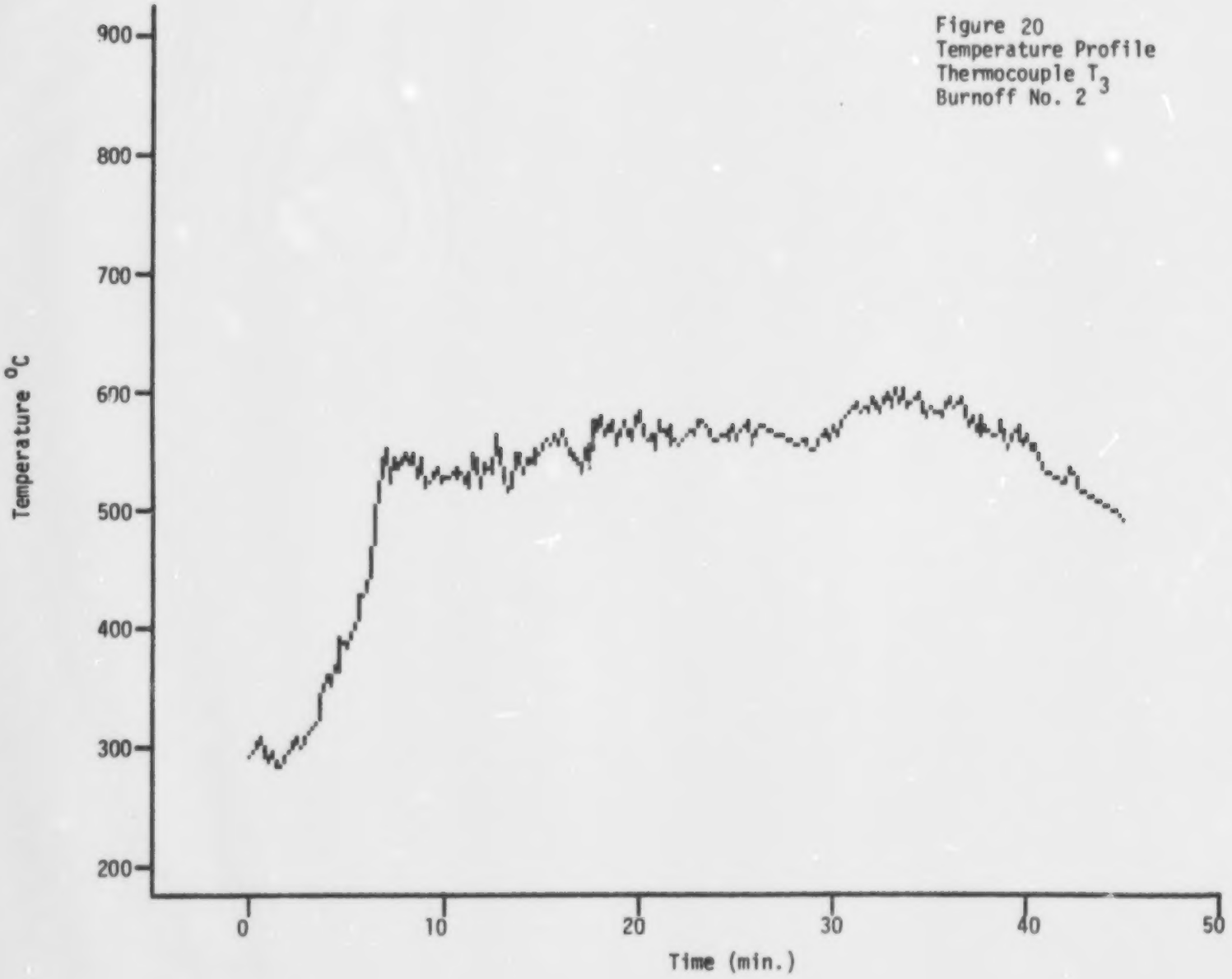

Figure 20
Temperature Profile
Thermocouple T_3
Burnoff No. 2

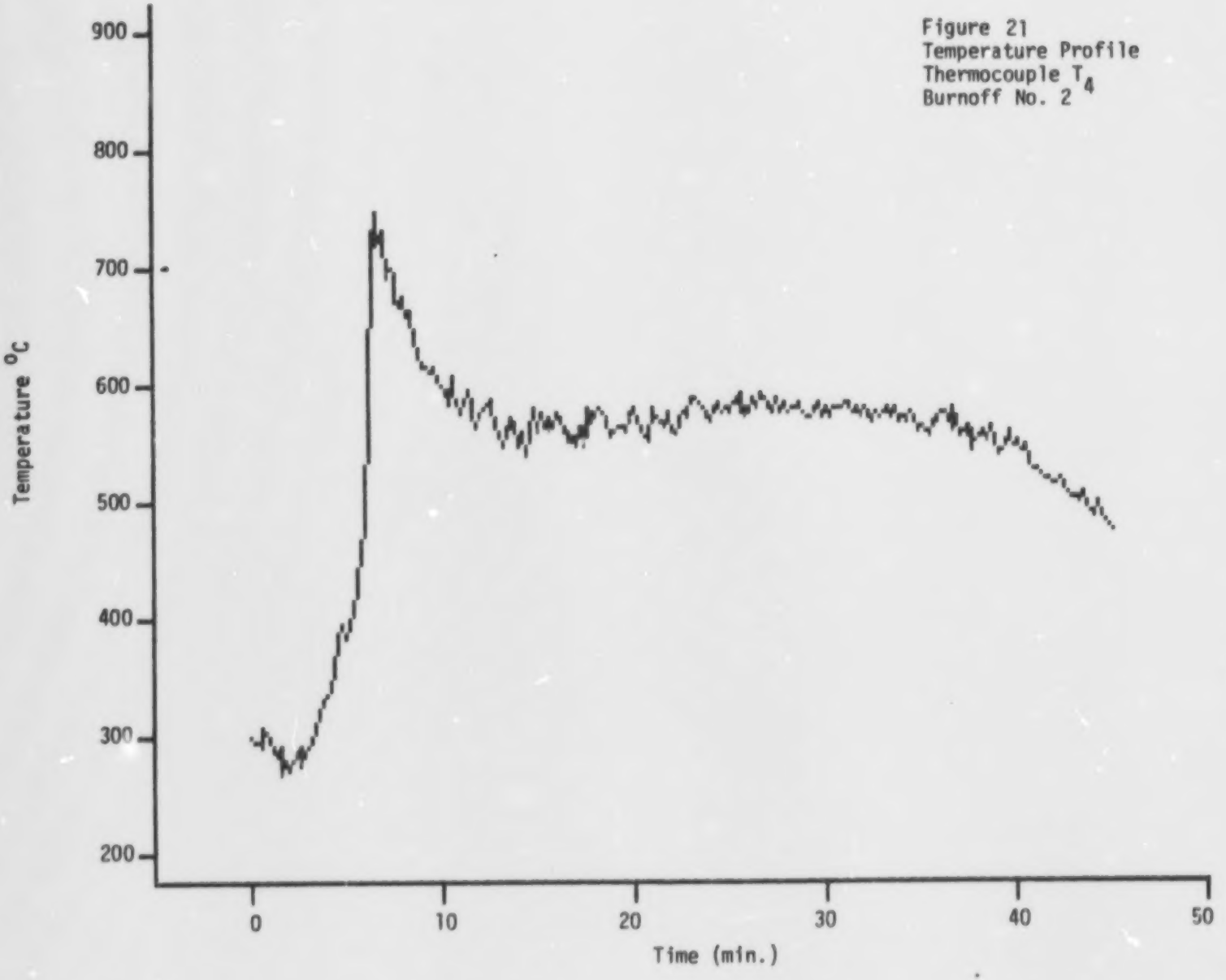

Figure 21
Temperature Profile
Thermocouple T_4
Burnoff No. 2

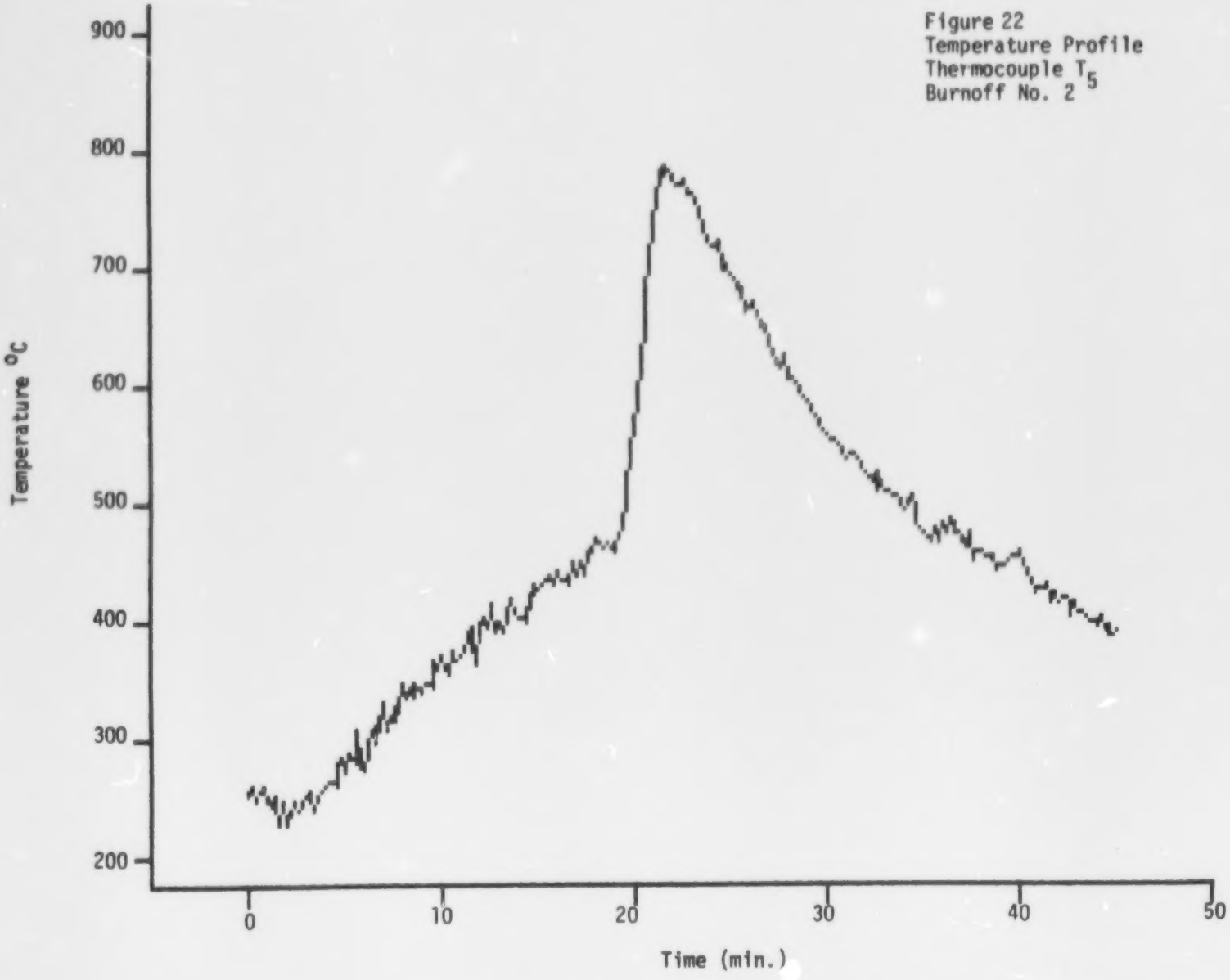

Figure 22
Temperature Profile
Thermocouple T_5
Burnoff No. 2

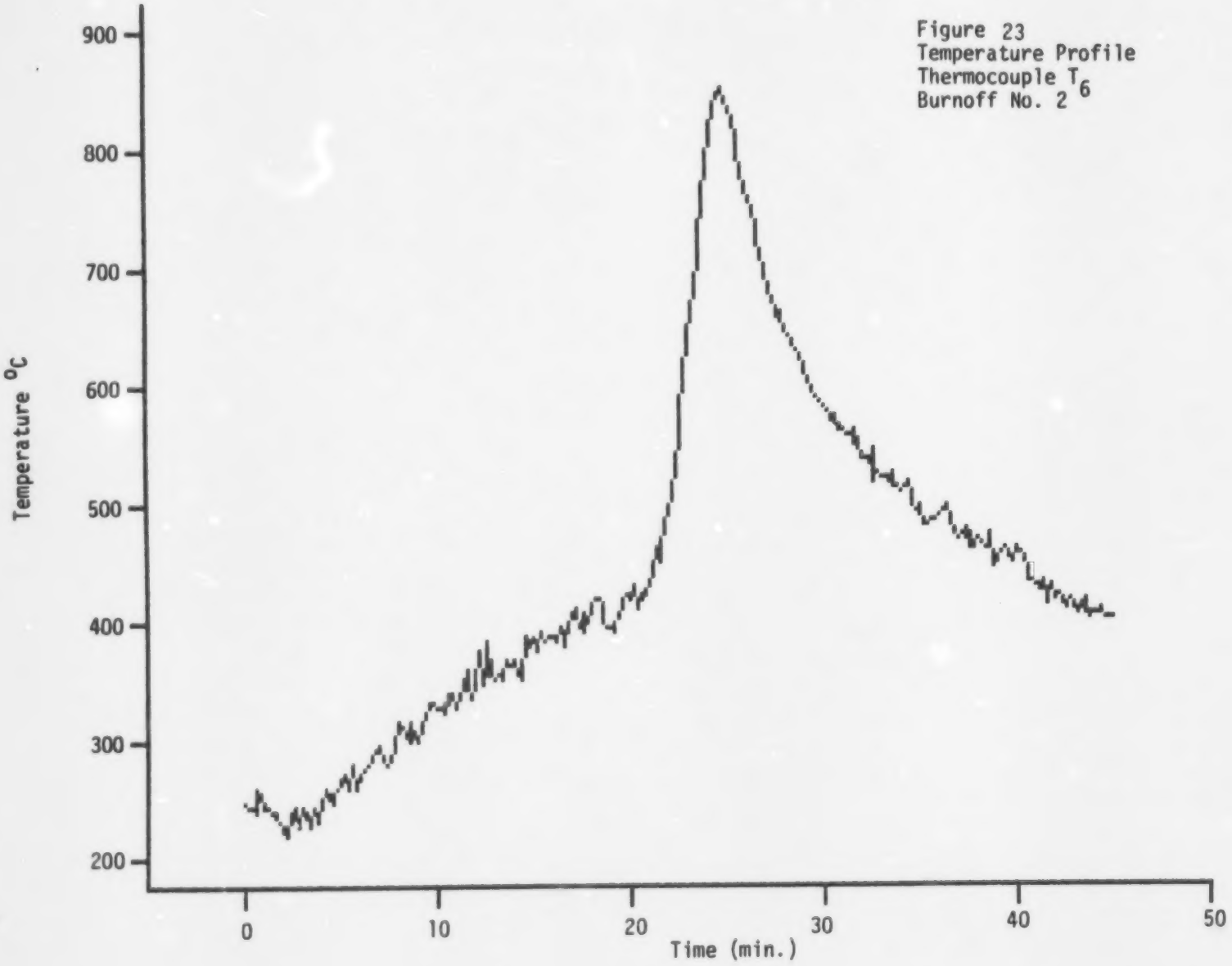

Figure 23
Temperature Profile
Thermocouple T_6
Burnoff No. 2

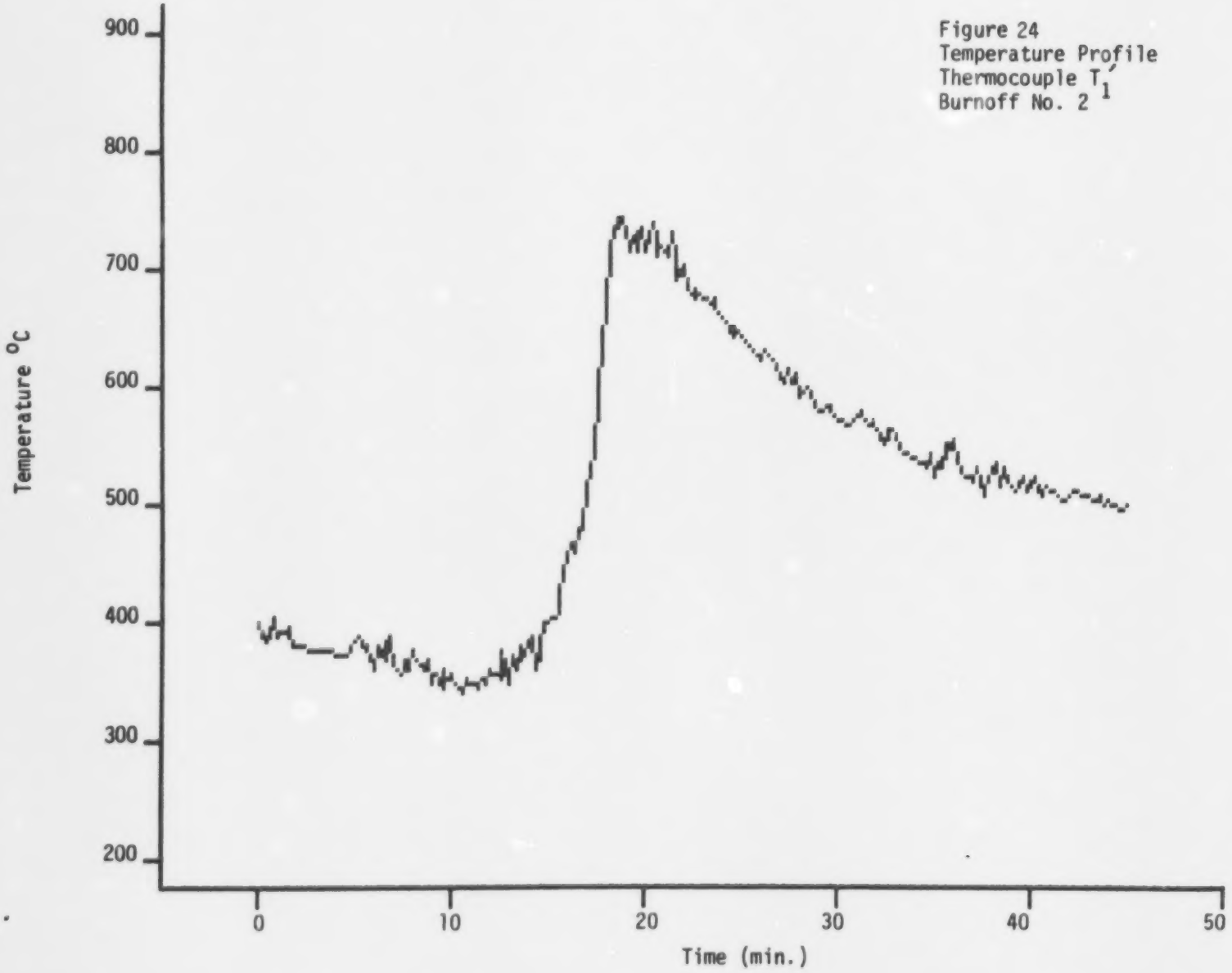

Figure 24
Temperature Profile
Thermocouple T_1'
Burnoff No. 2

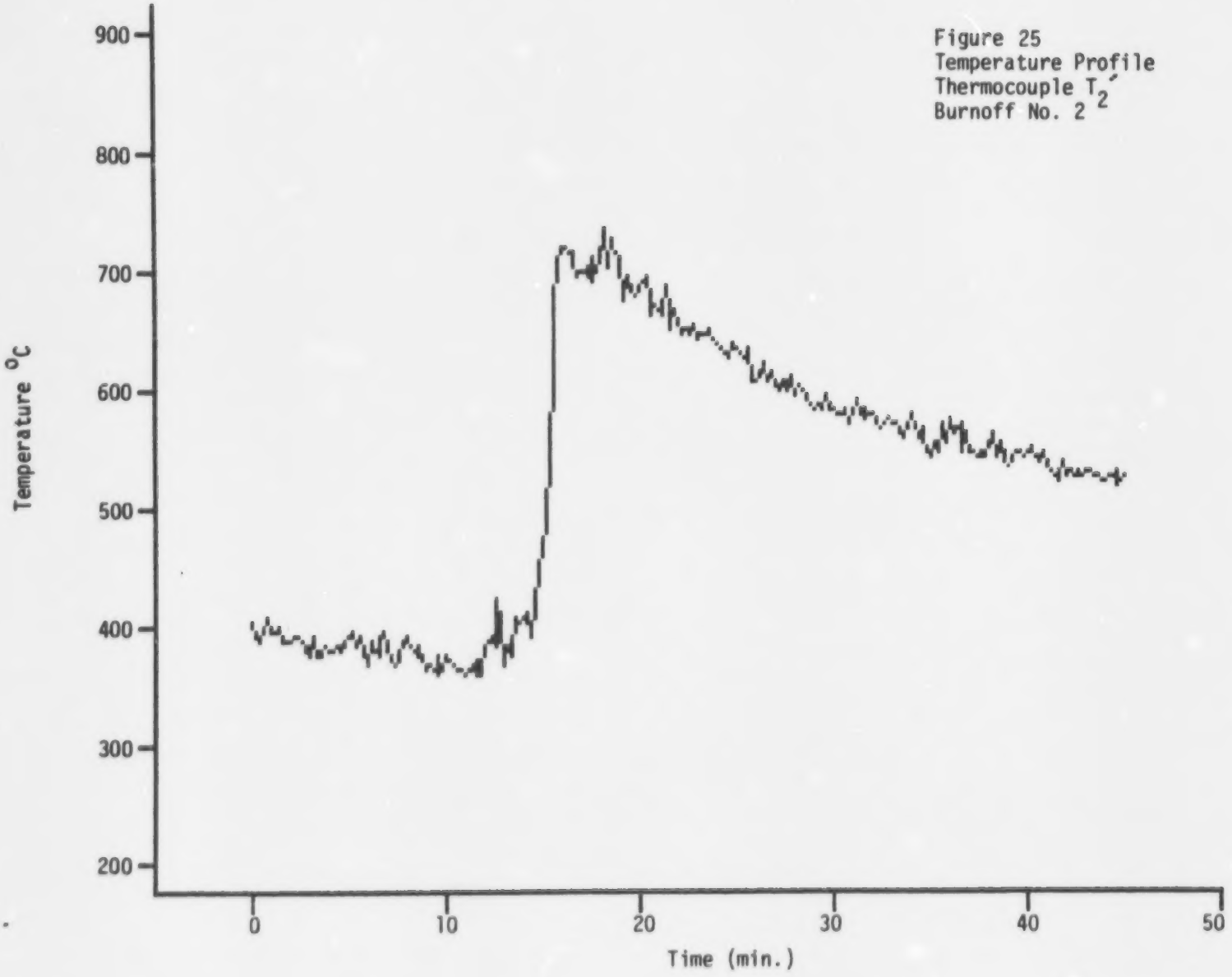

Figure 25
Temperature Profile
Thermocouple T_2'
Burnoff No. 2

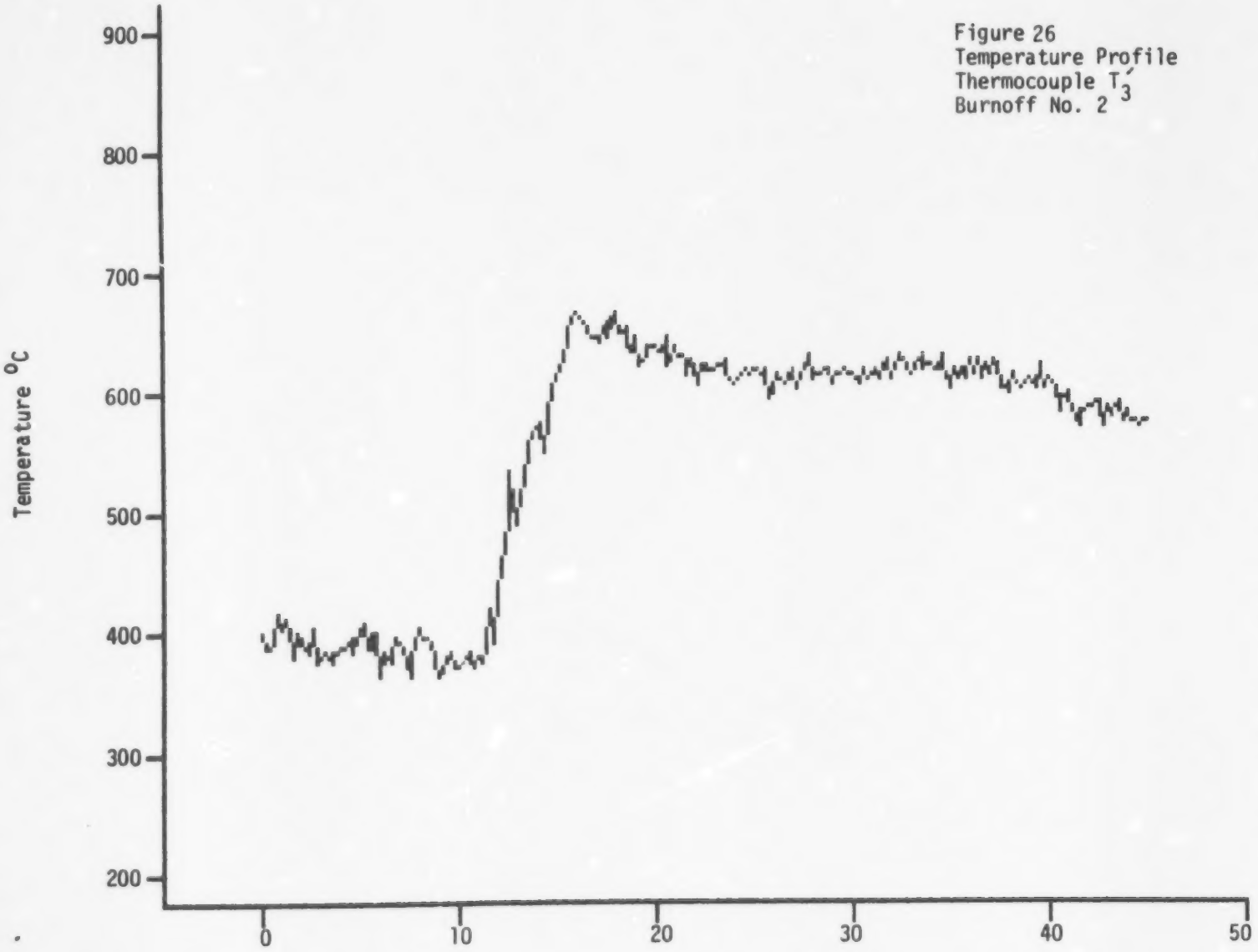

Figure 26
Temperature Profile
Thermocouple T_3'
Burnoff No. 2

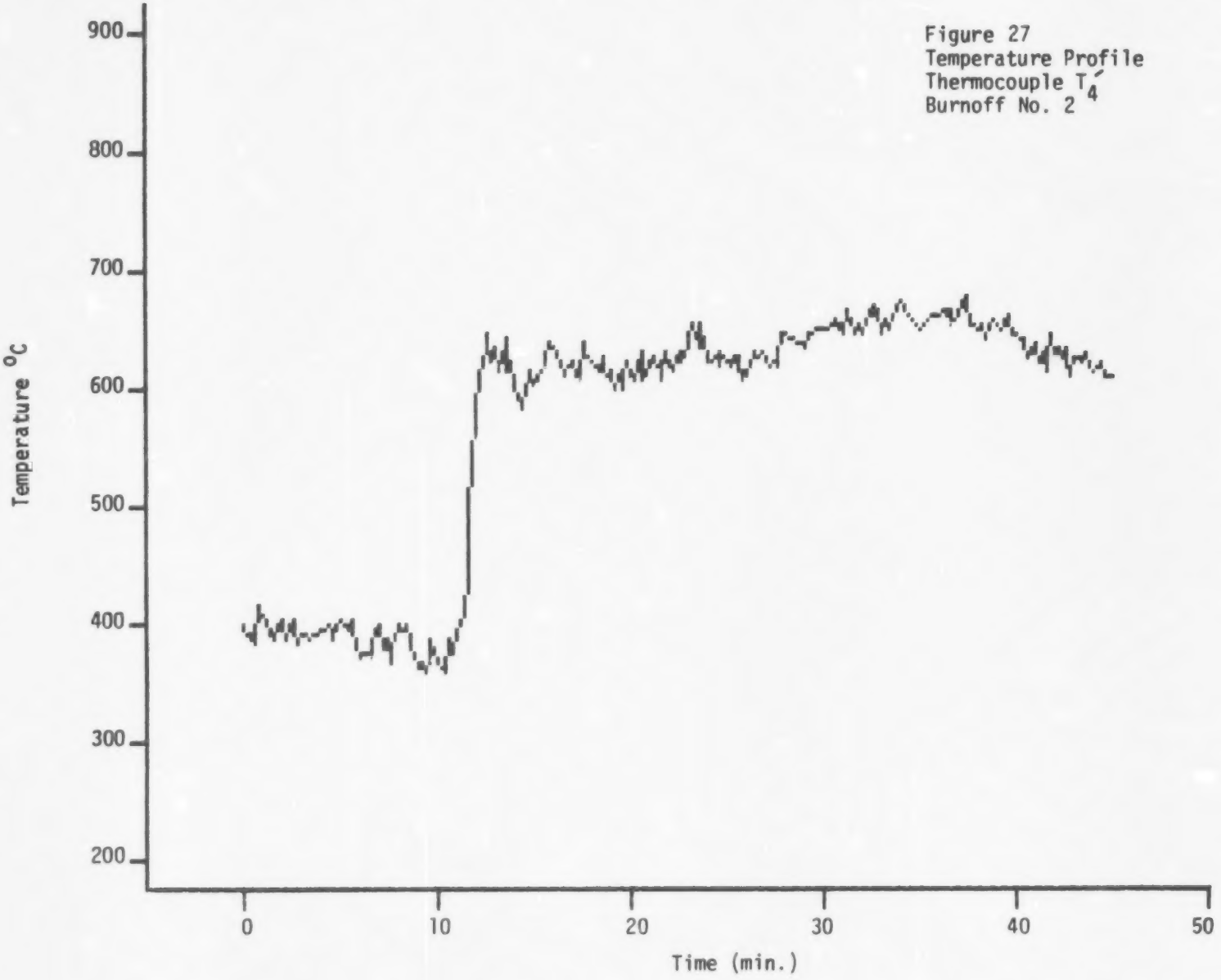

Figure 27
Temperature Profile
Thermocouple T_4'
Burnoff No. 2

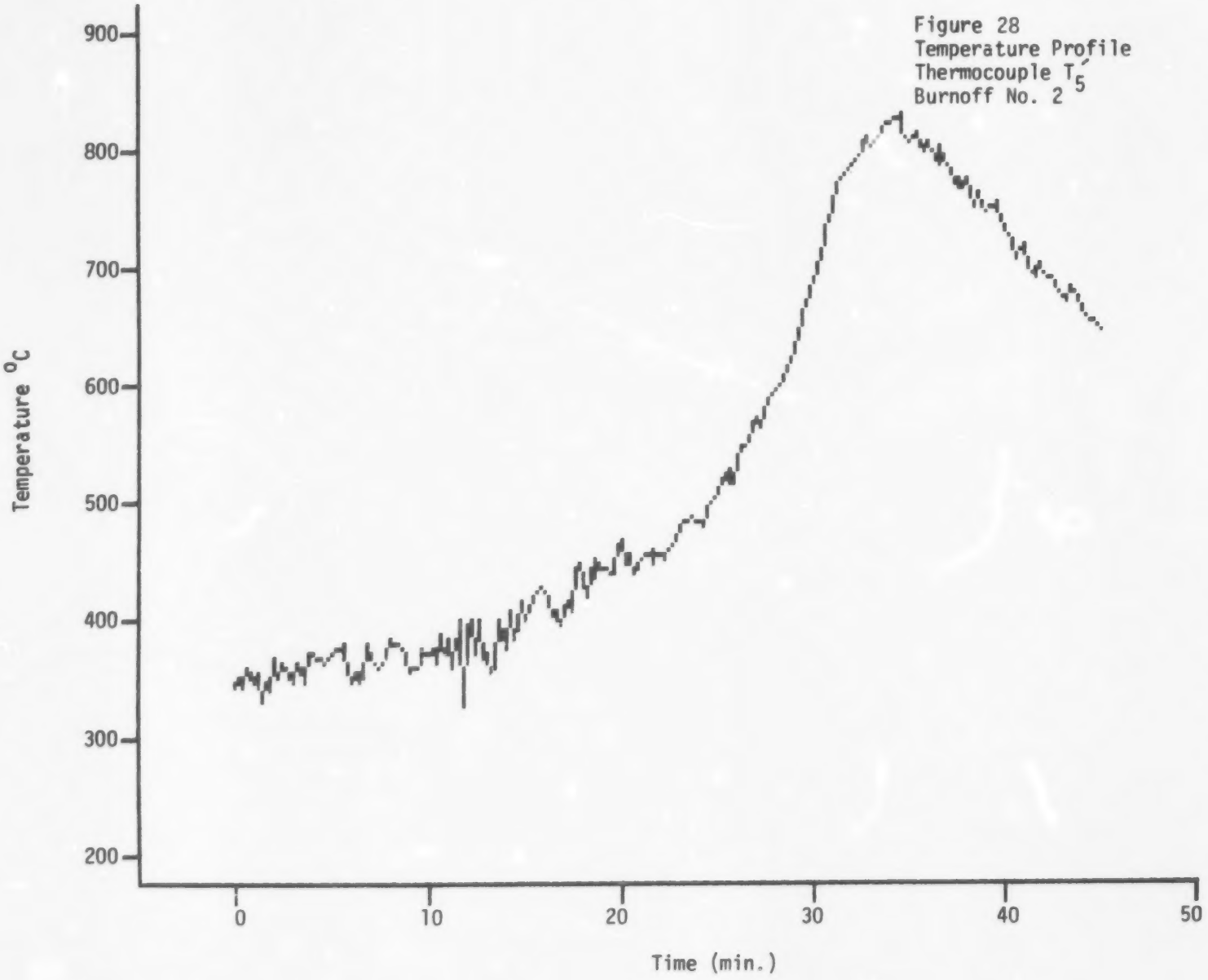

Figure 28
Temperature Profile
Thermocouple T_5'
Burnoff No. 2

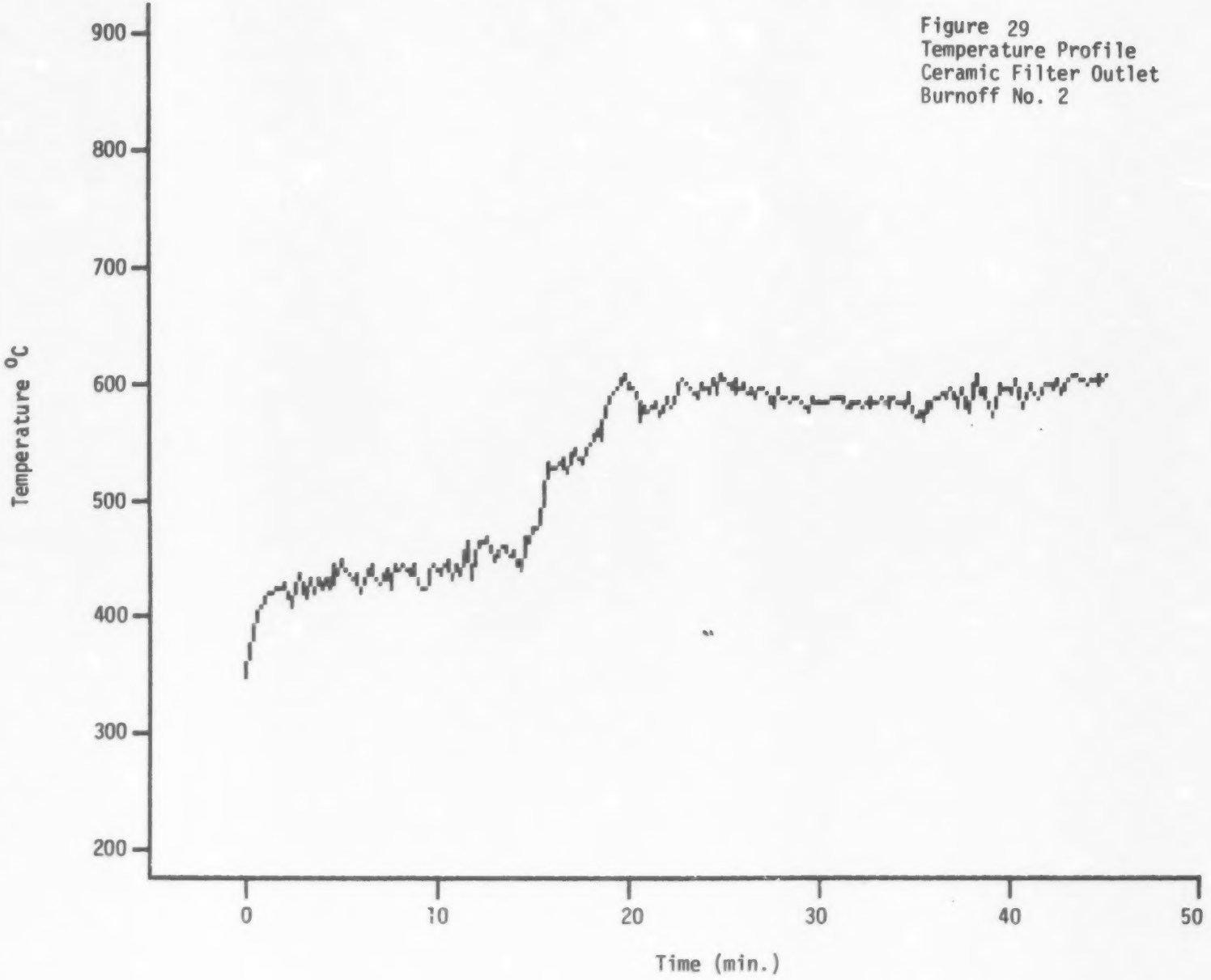

Figure 29
Temperature Profile
Ceramic Filter Outlet
Burnoff No. 2

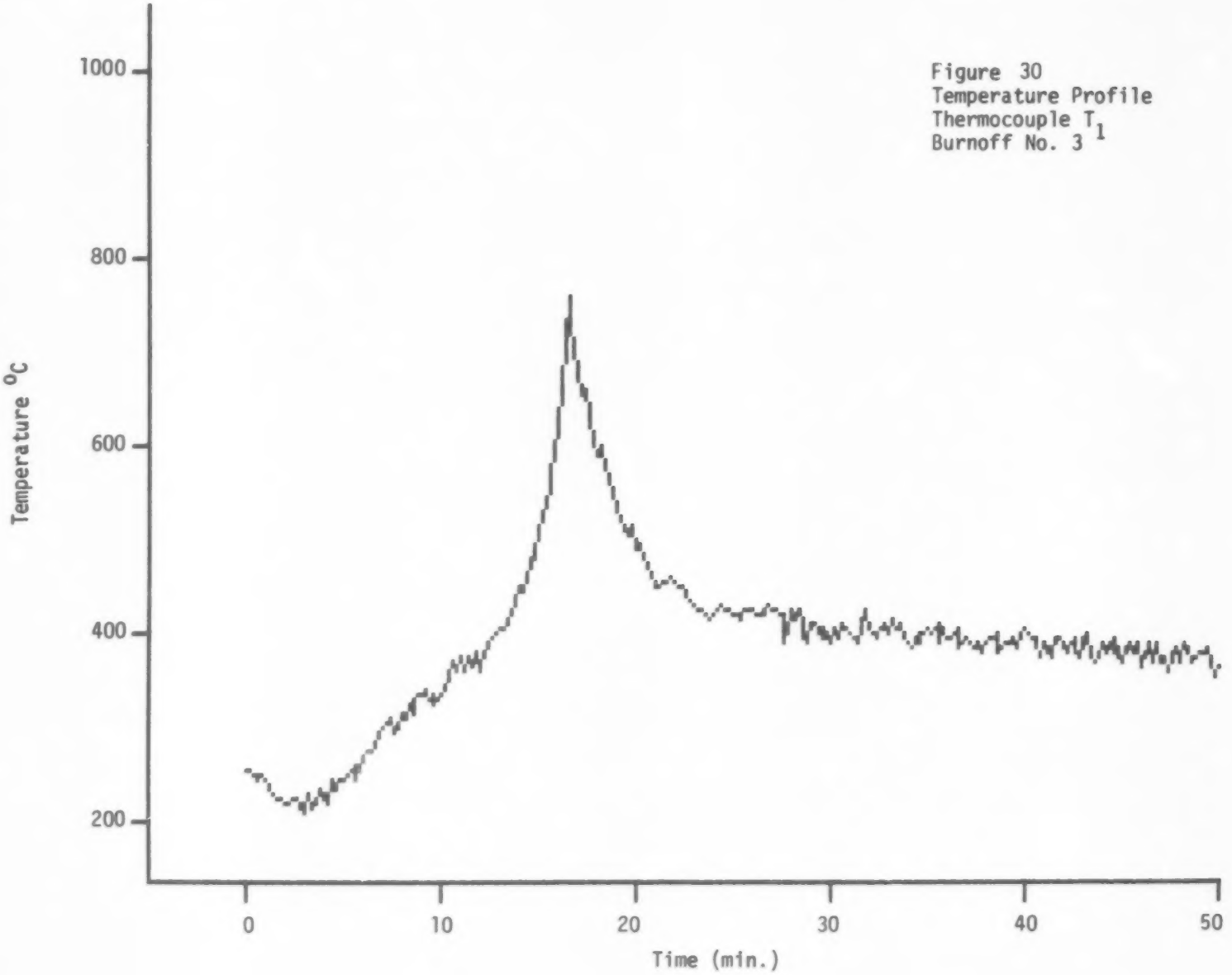

Figure 30
Temperature Profile
Thermocouple T_1
Burnoff No. 3

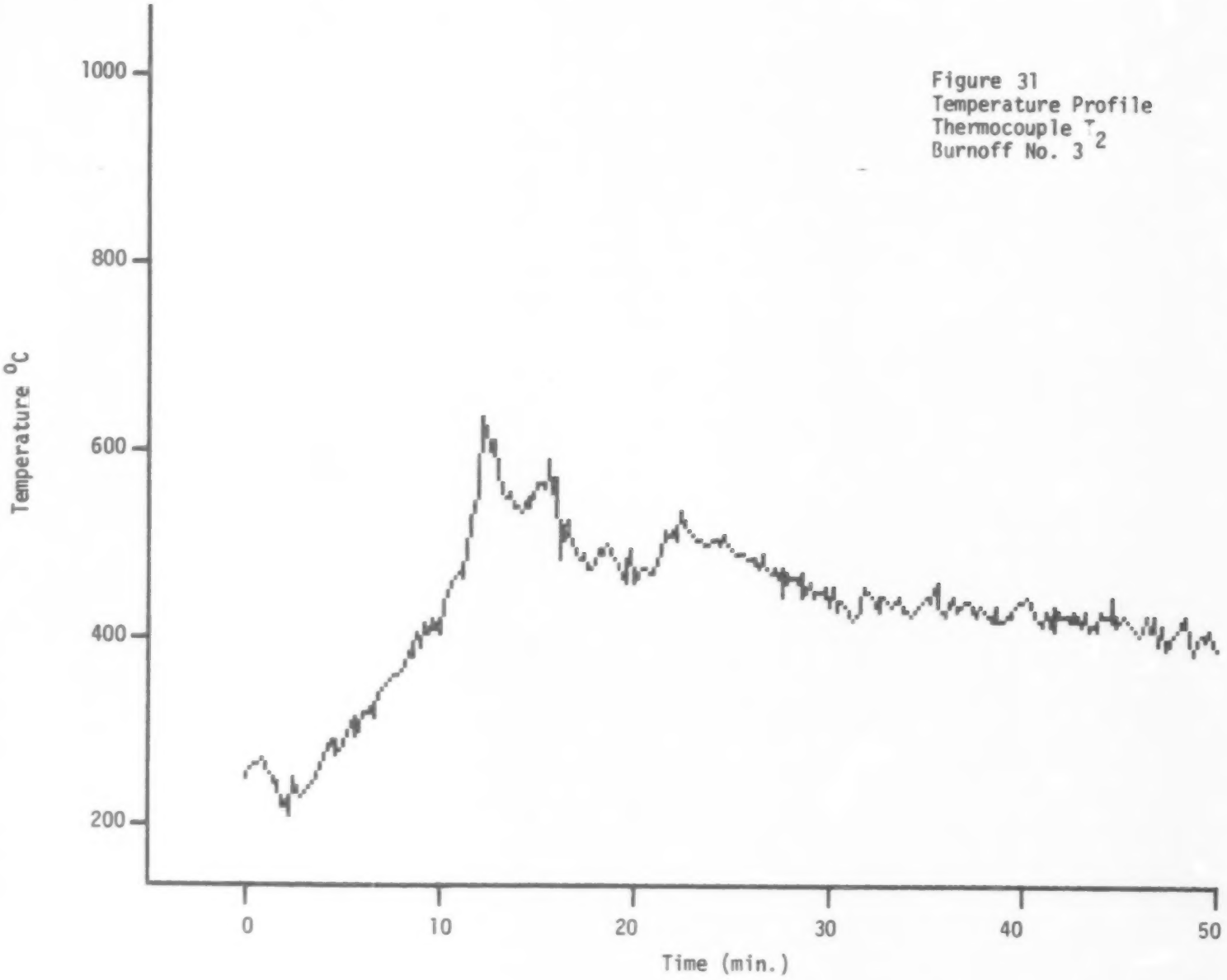

Figure 31
Temperature Profile
Thermocouple T_2
Burnoff No. 3

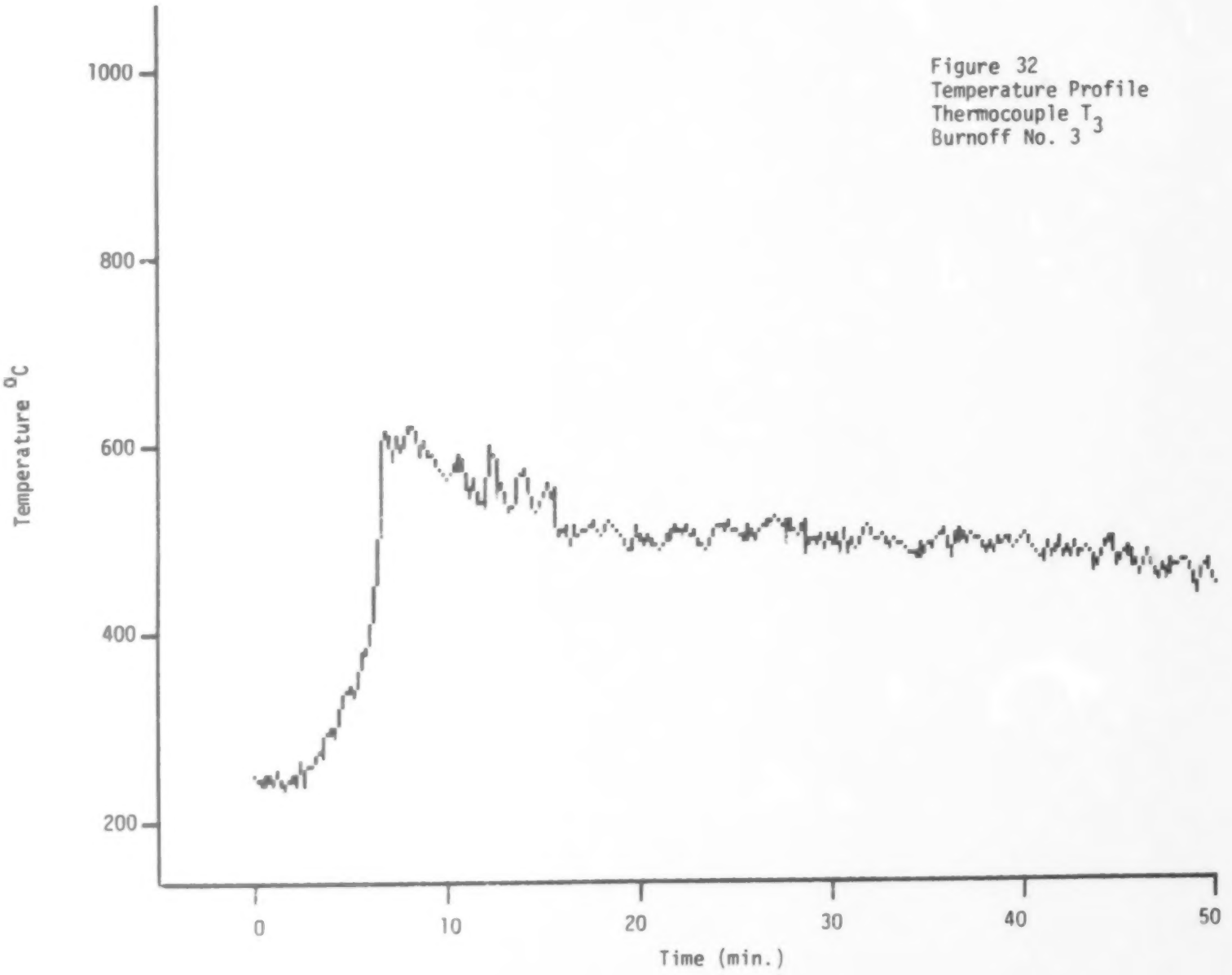

Figure 32
Temperature Profile
Thermocouple T_3
Burnoff No. 3

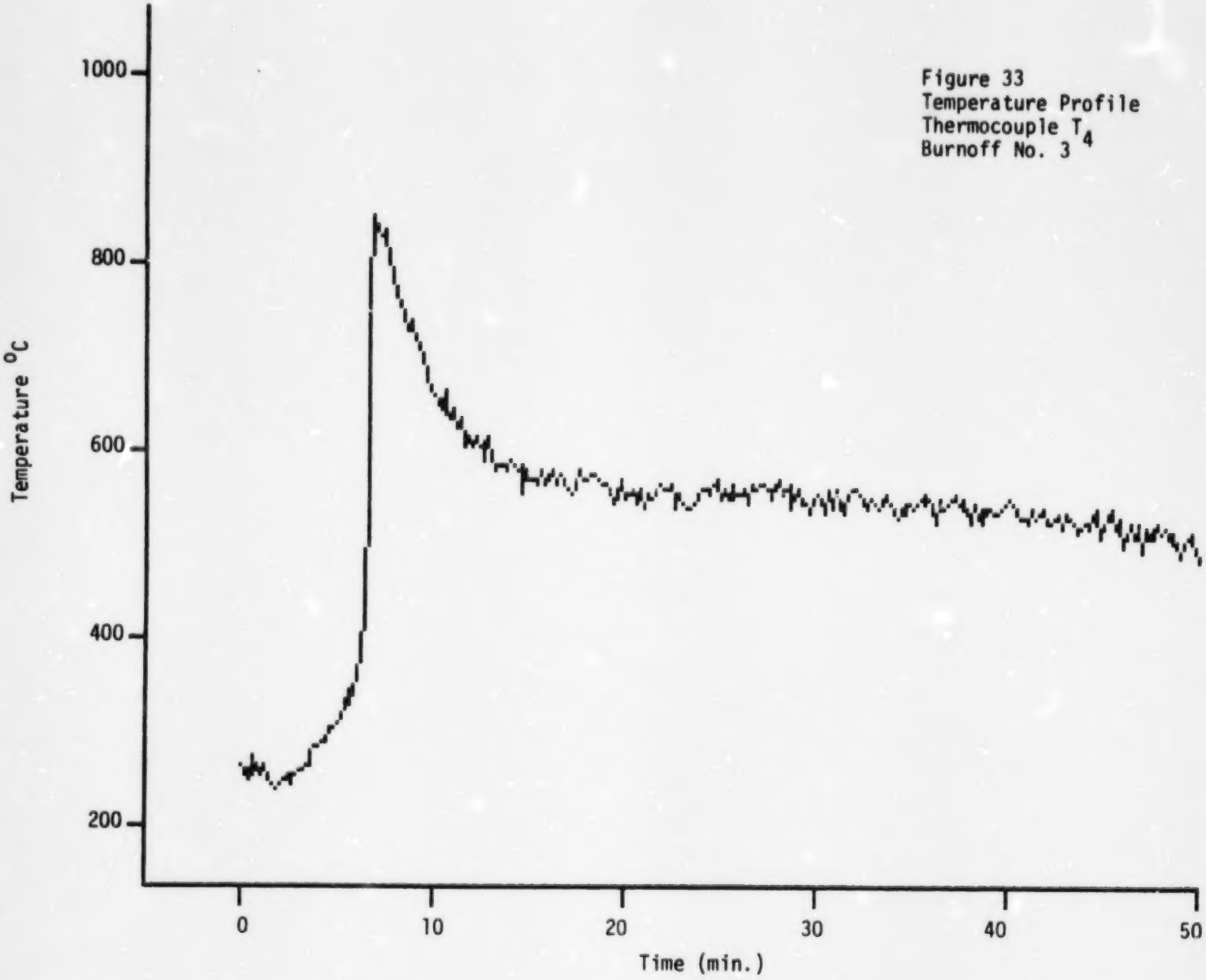

Figure 33
Temperature Profile
Thermocouple T_4
Burnoff No. 3

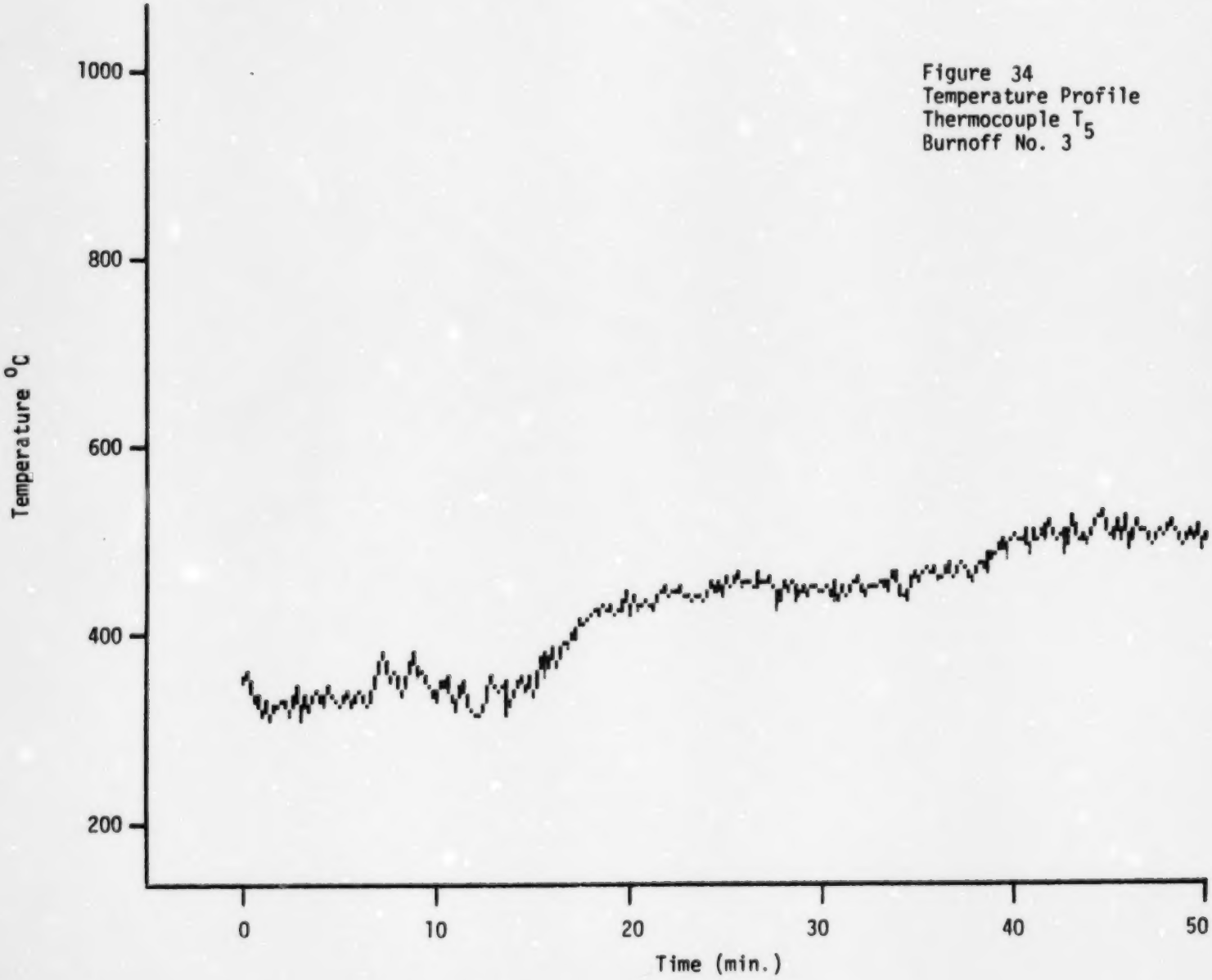

Figure 34
Temperature Profile
Thermocouple T_5
Burnoff No. 3

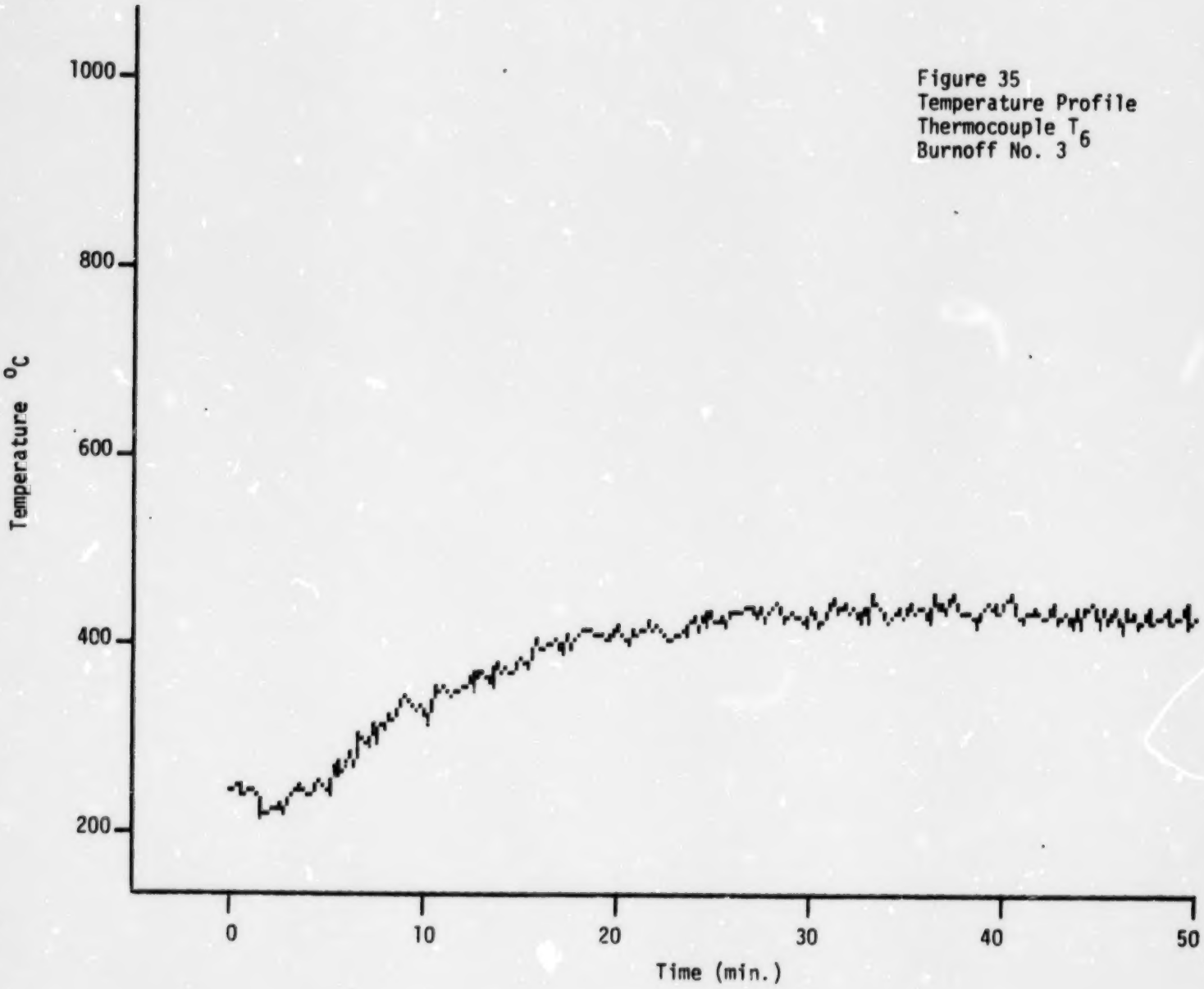

Figure 35
Temperature Profile
Thermocouple T_6
Burnoff No. 3

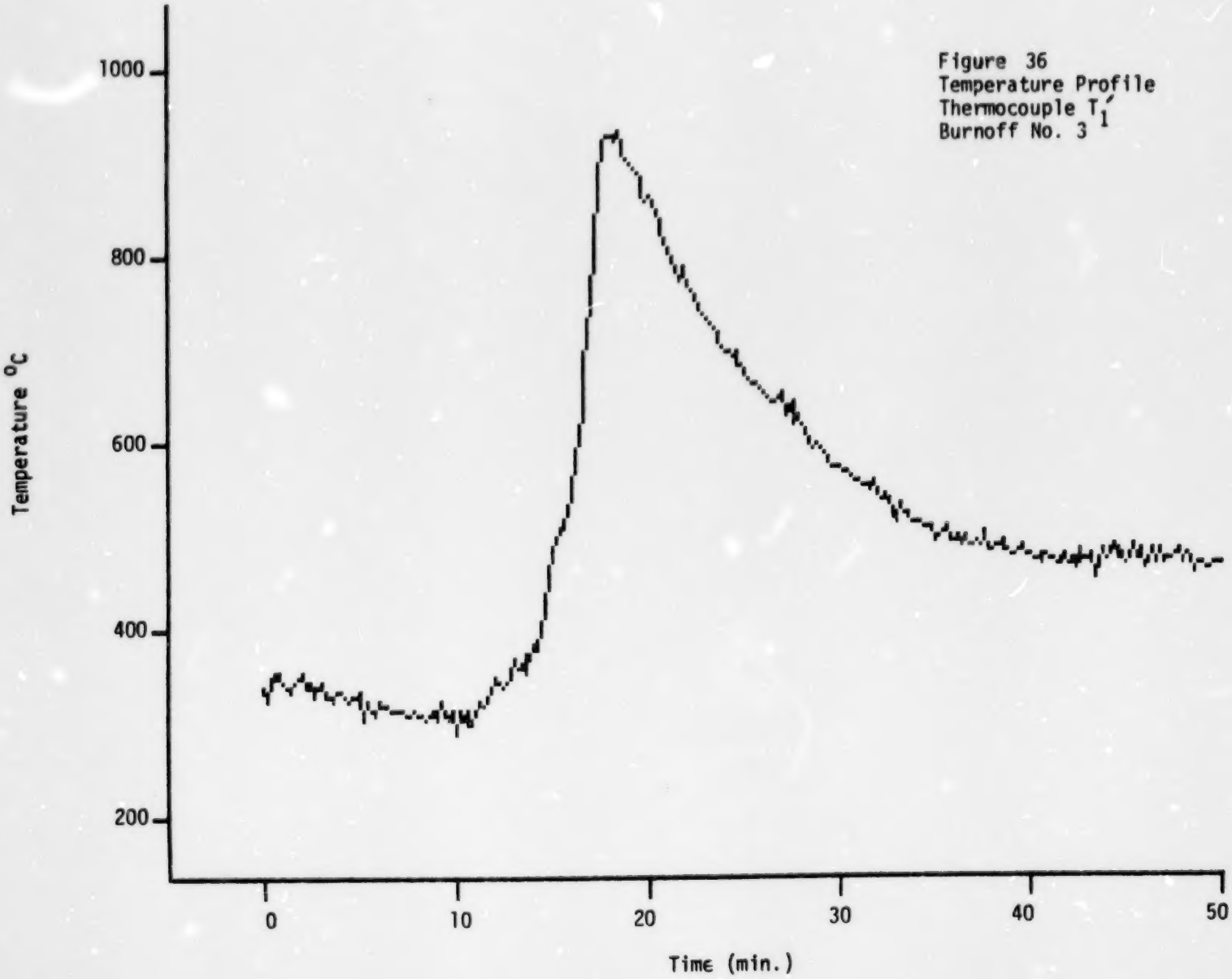

Figure 36
Temperature Profile
Thermocouple T_1'
Burnoff No. 3

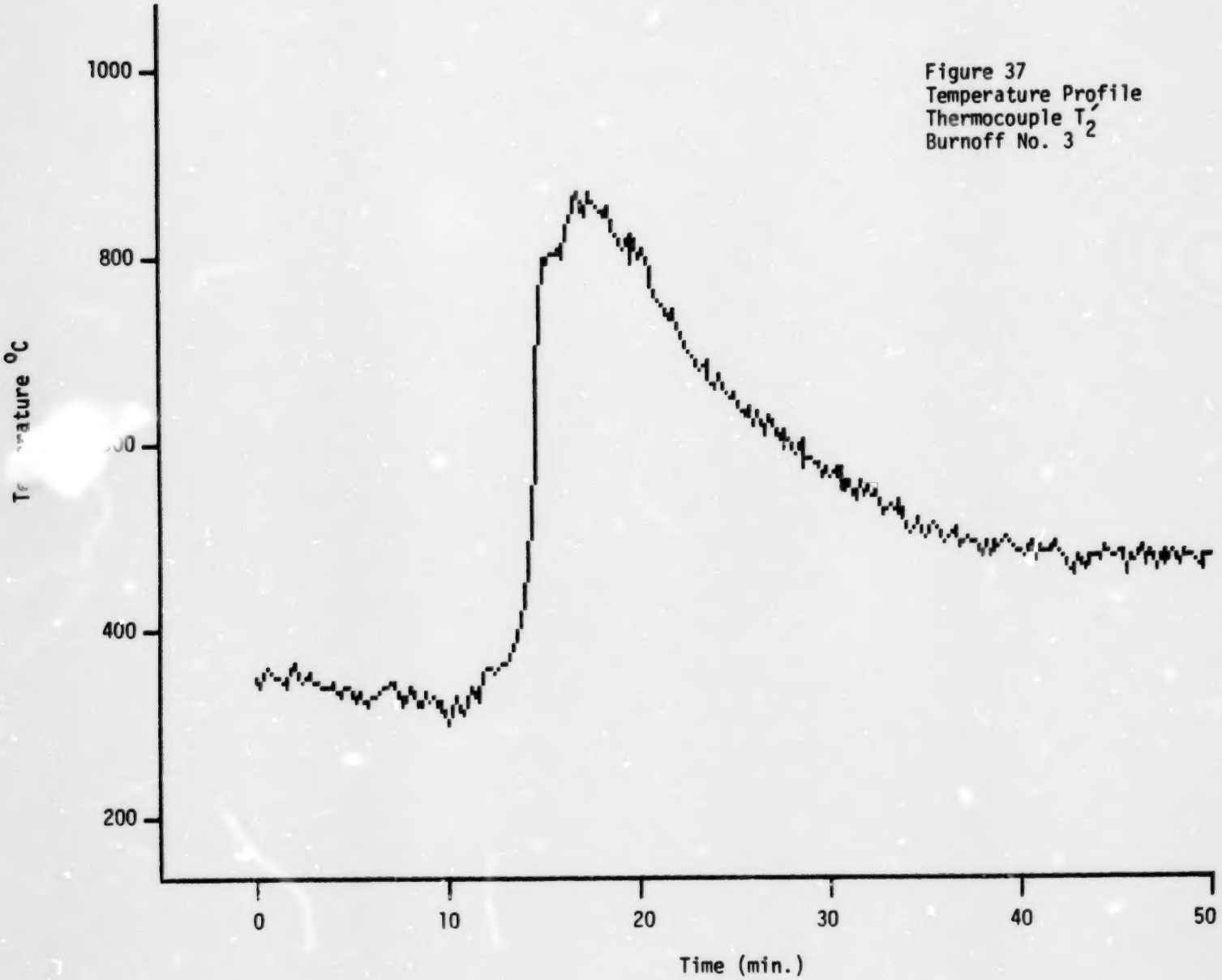

Figure 37
Temperature Profile
Thermocouple T_2'
Burnoff No. 3

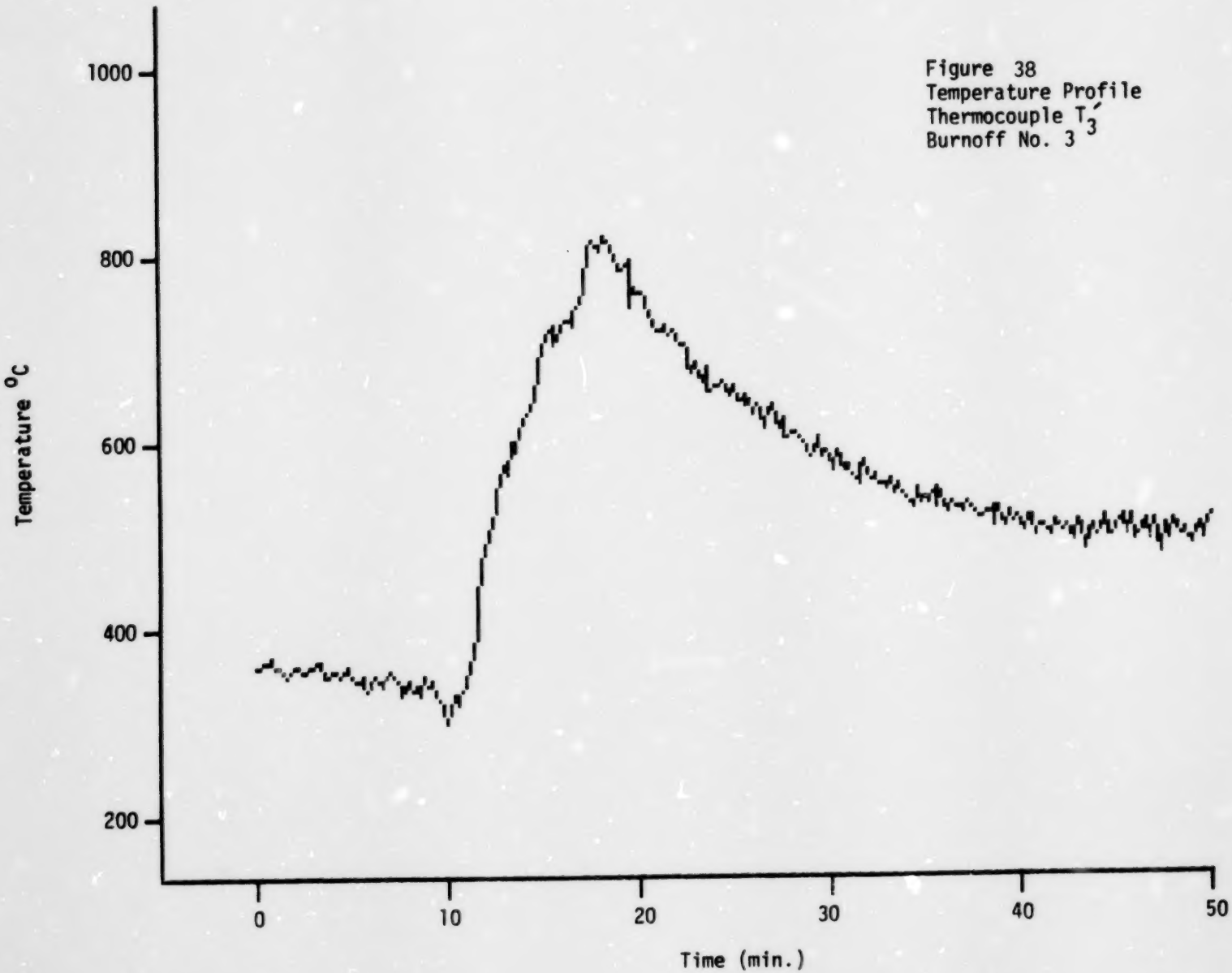

Figure 38
Temperature Profile
Thermocouple T_3'
Burnoff No. 3

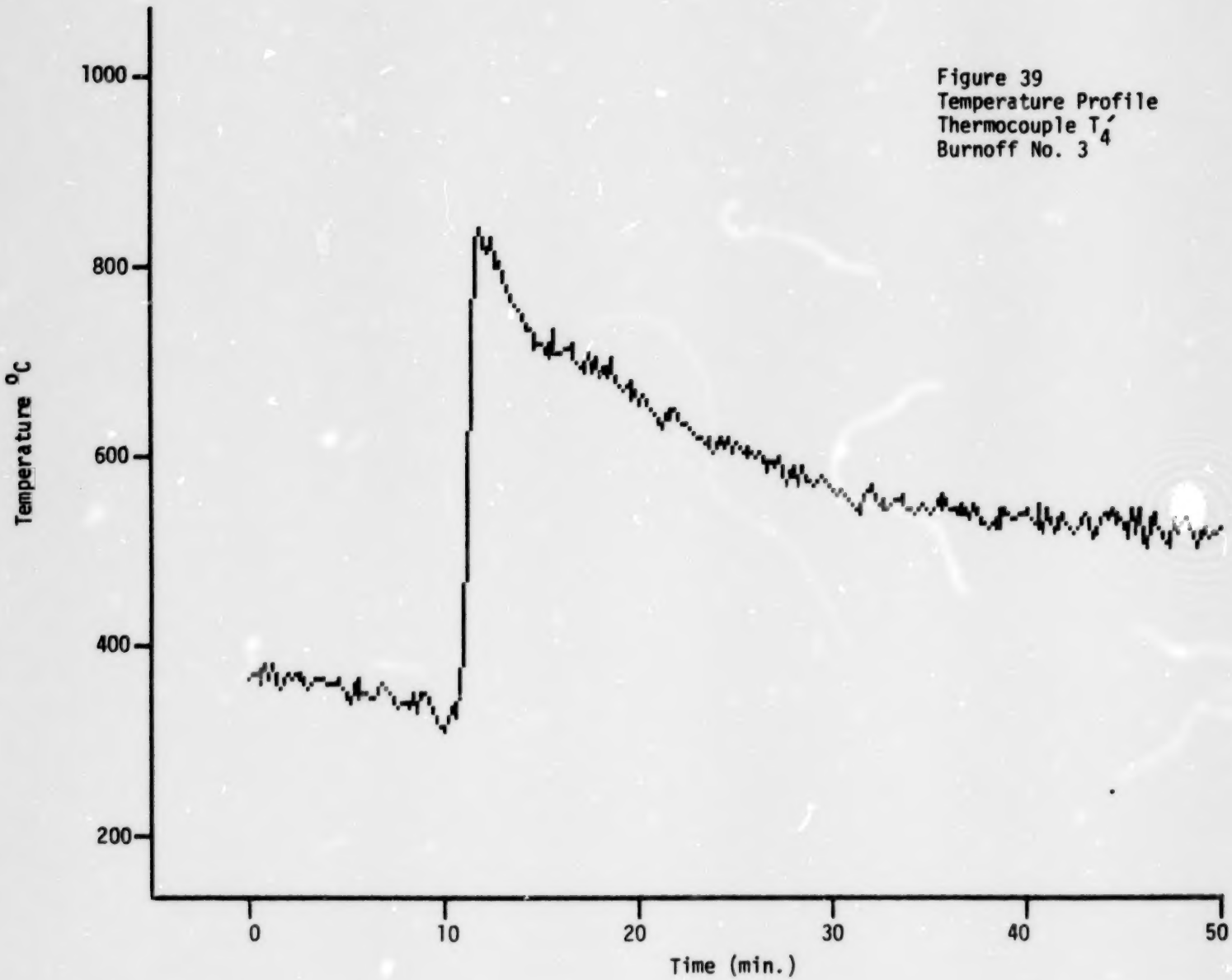

Figure 39
Temperature Profile
Thermocouple T_4'
Burnoff No. 3

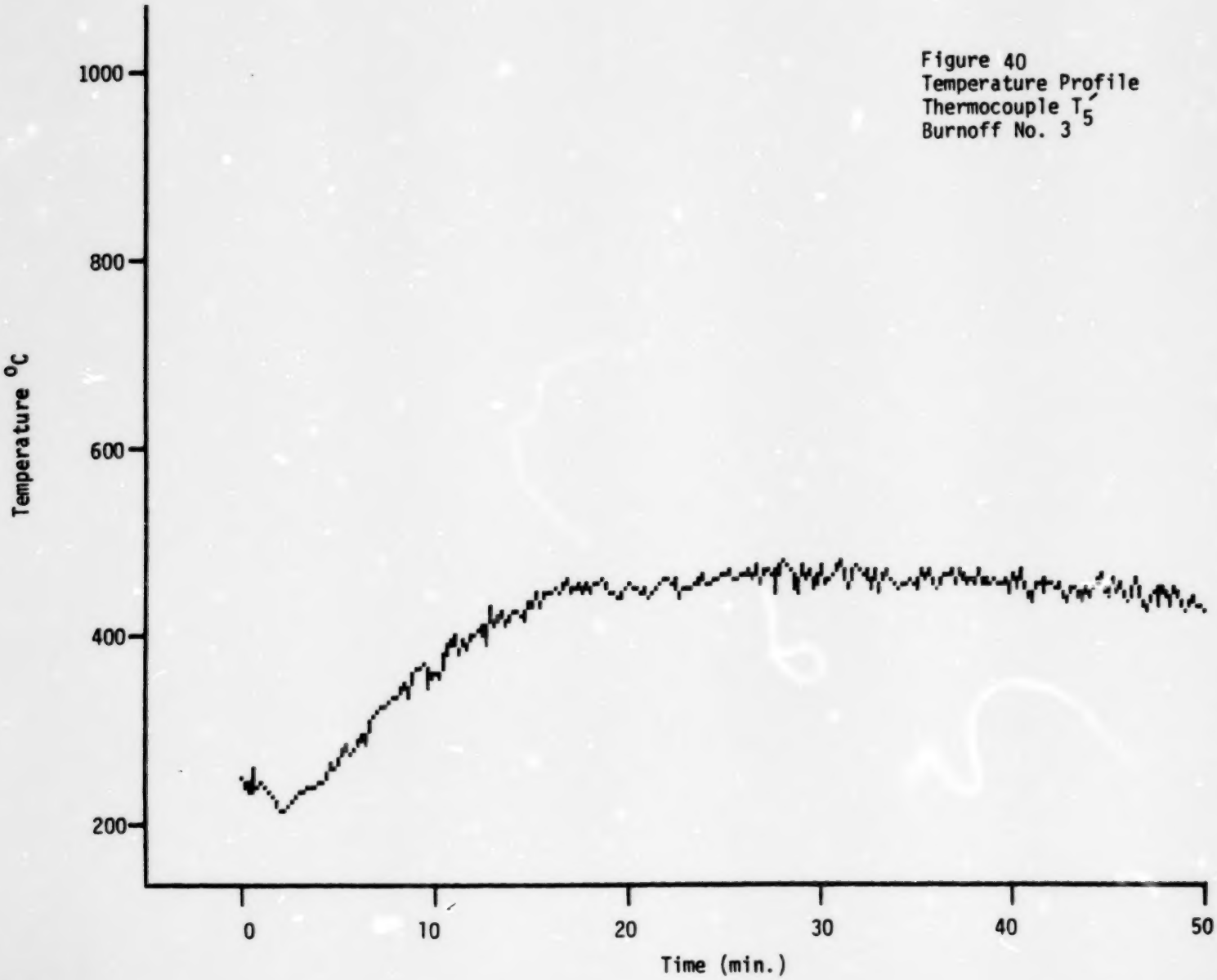

Figure 40
Temperature Profile
Thermocouple T_5'
Burnoff No. 3

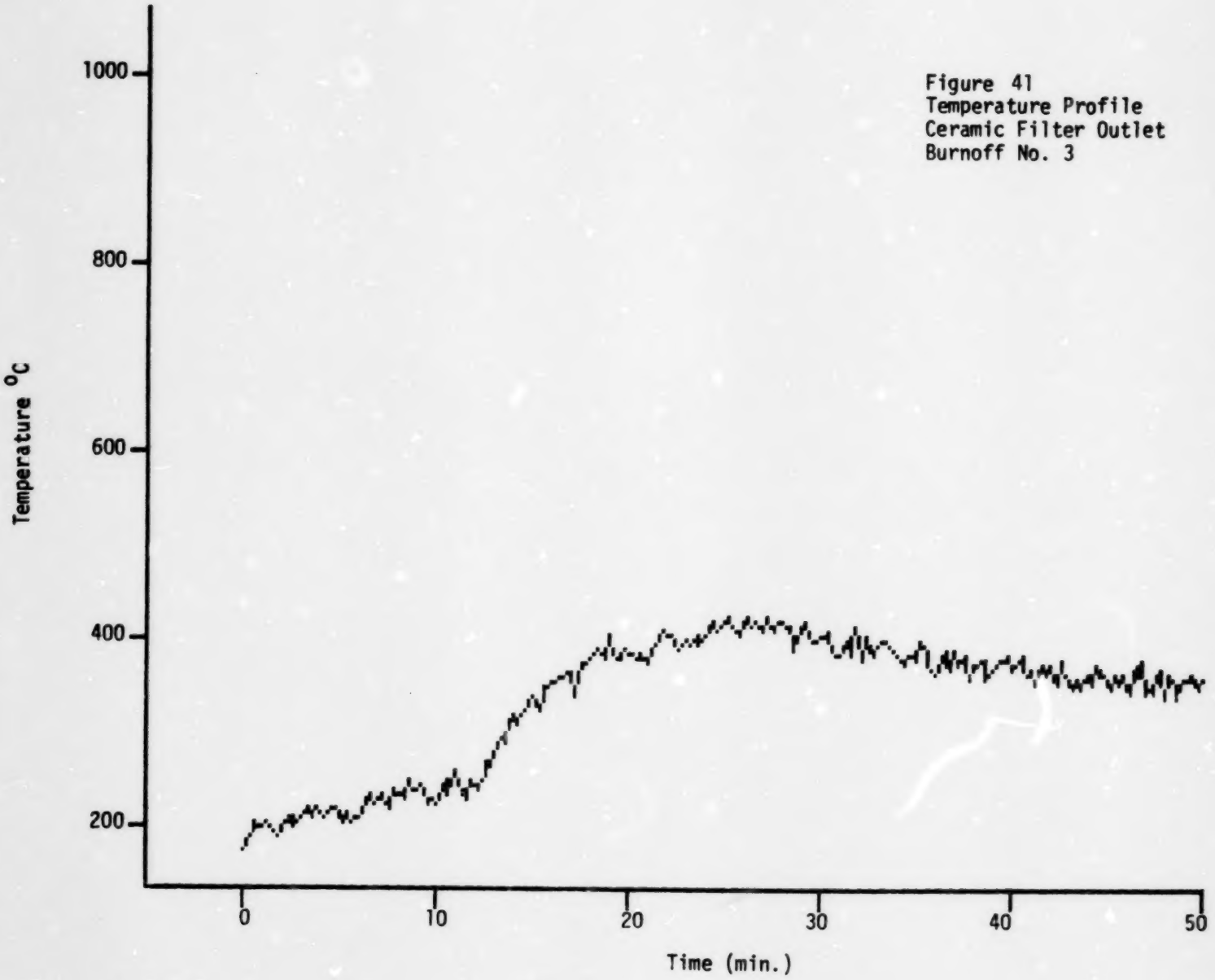

Figure 41
Temperature Profile
Ceramic Filter Outlet
Burnoff No. 3

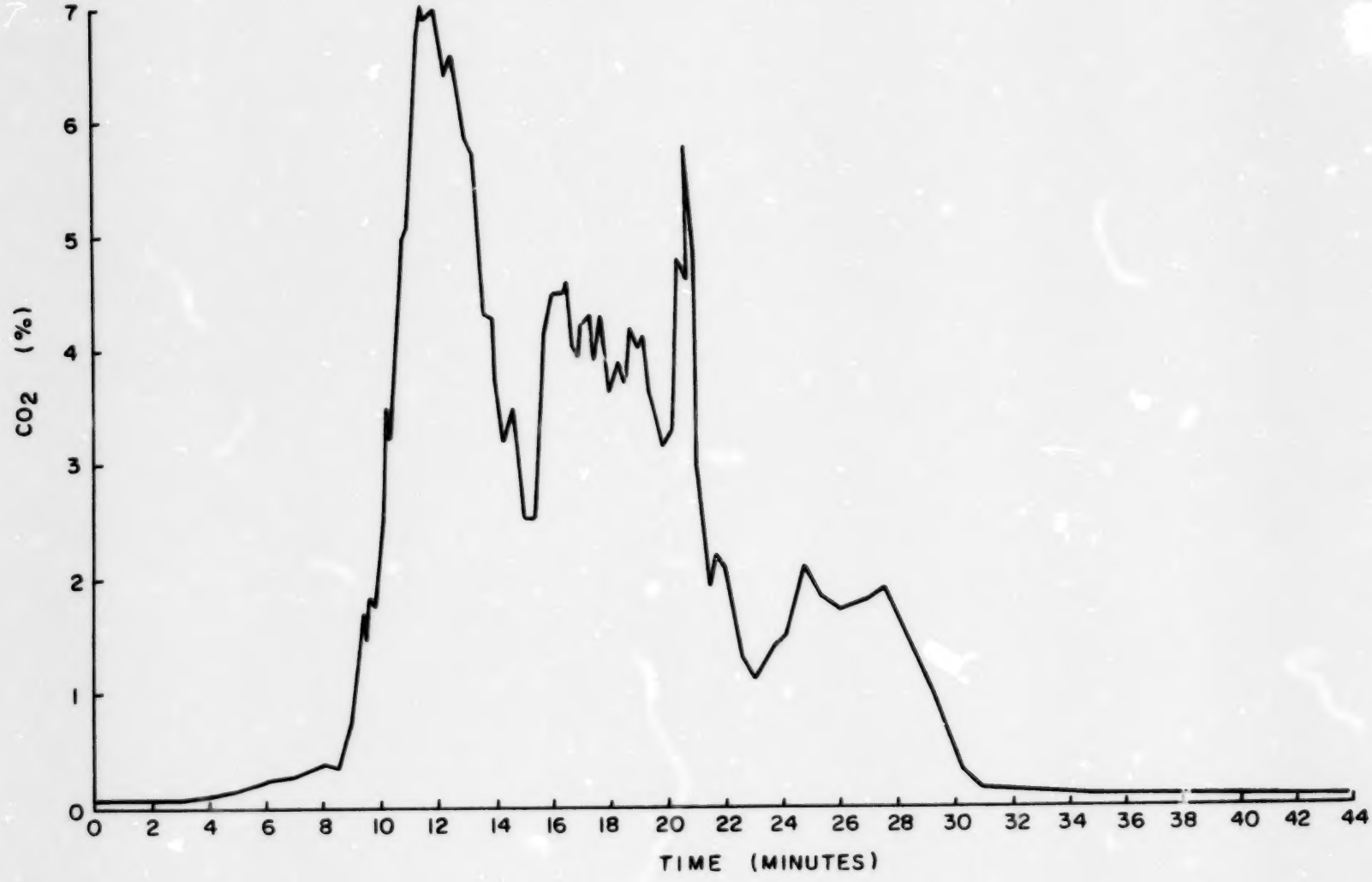

FIGURE 42 CARBON DIOXIDE CONCENTRATION vs TIME - BURNOFF No. 1.

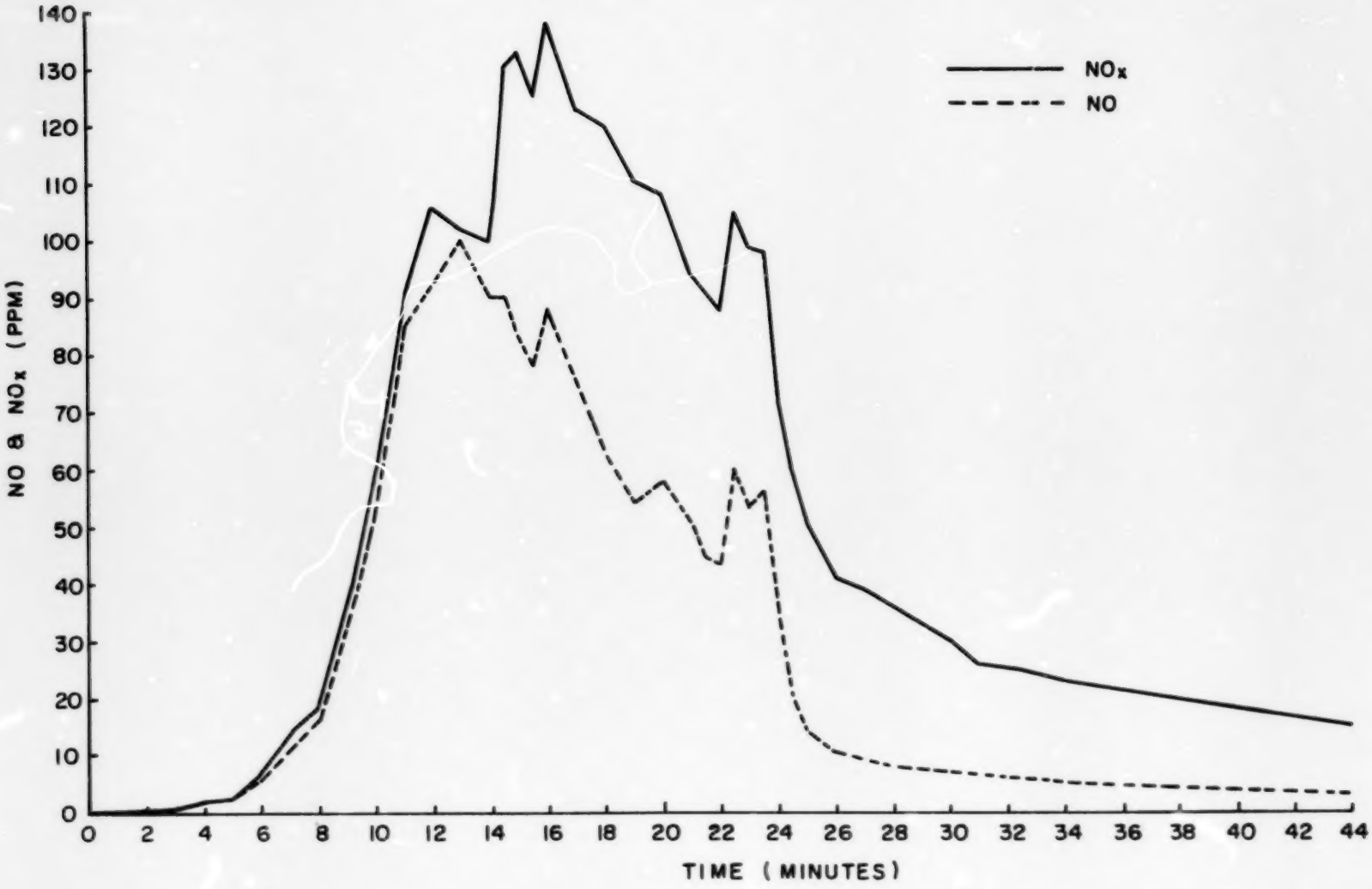

FIGURE 43 CONCENTRATIONS OF NO & NO_x vs TIME - BURNOFF No.1

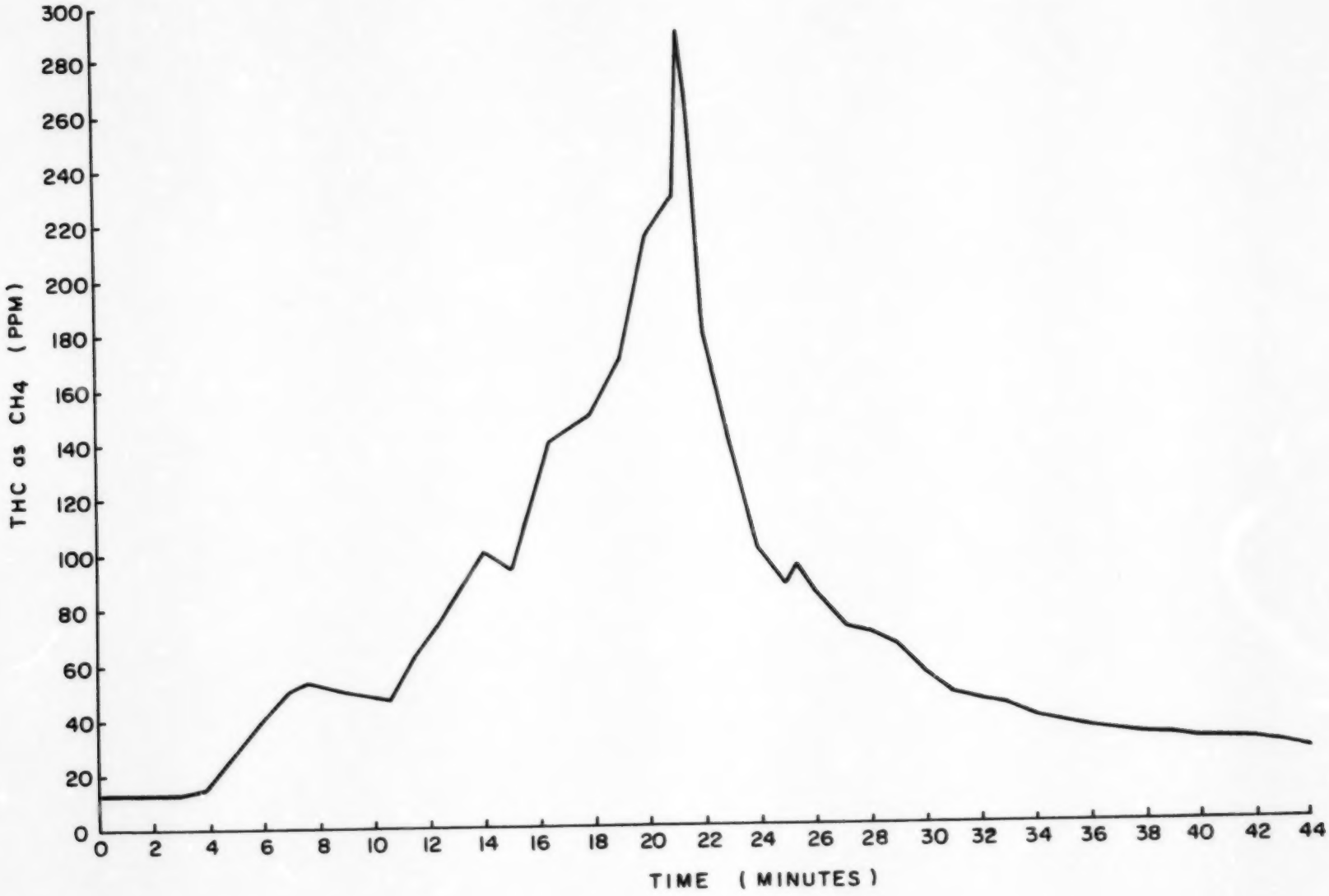

FIGURE 44 TOTAL HYDROCARBON CONCENTRATION vs TIME - BURNOFF No. 1.

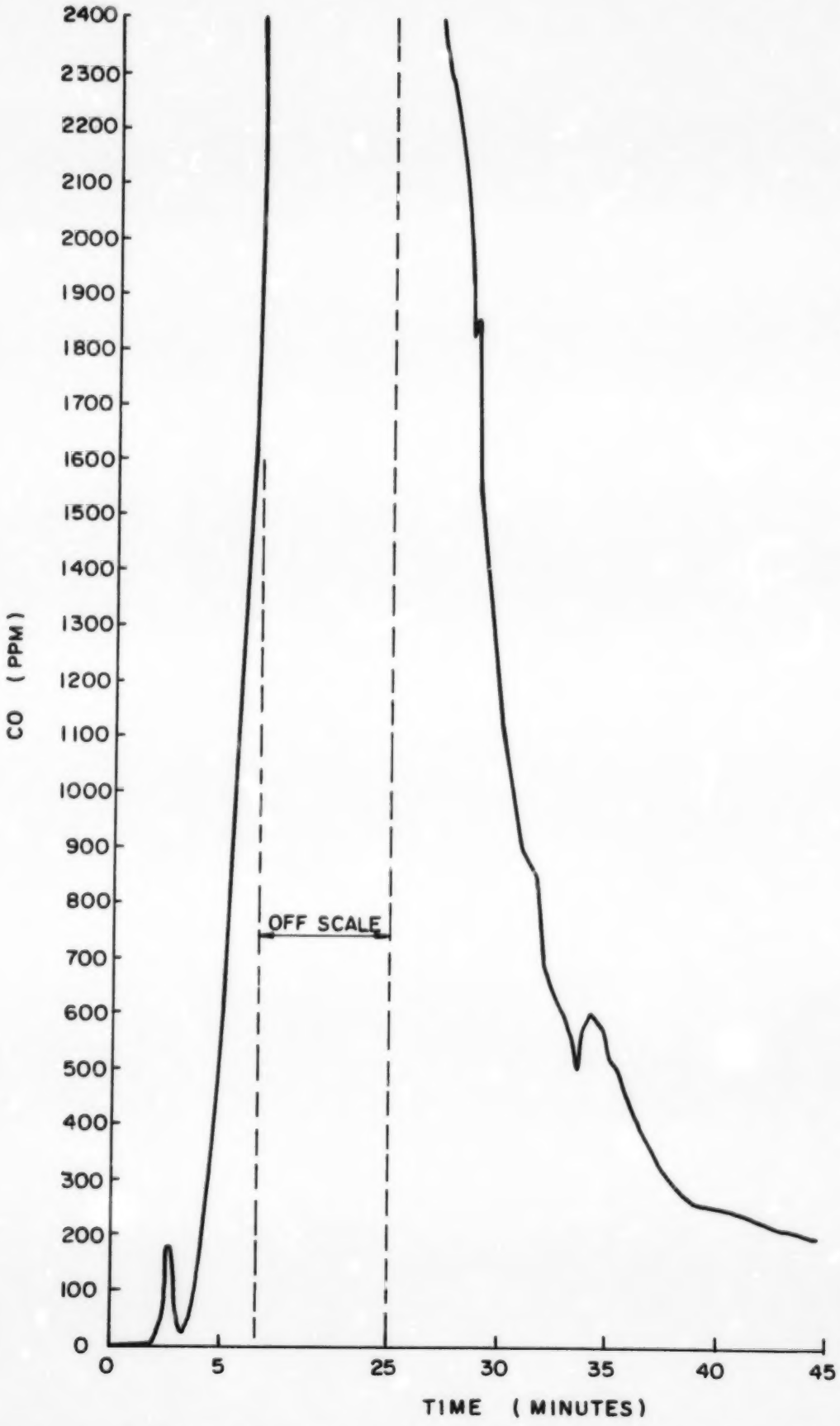

FIGURE 45 CARBON MONOXIDE CONCENTRATION vs TIME - BURNOFF No. 1.

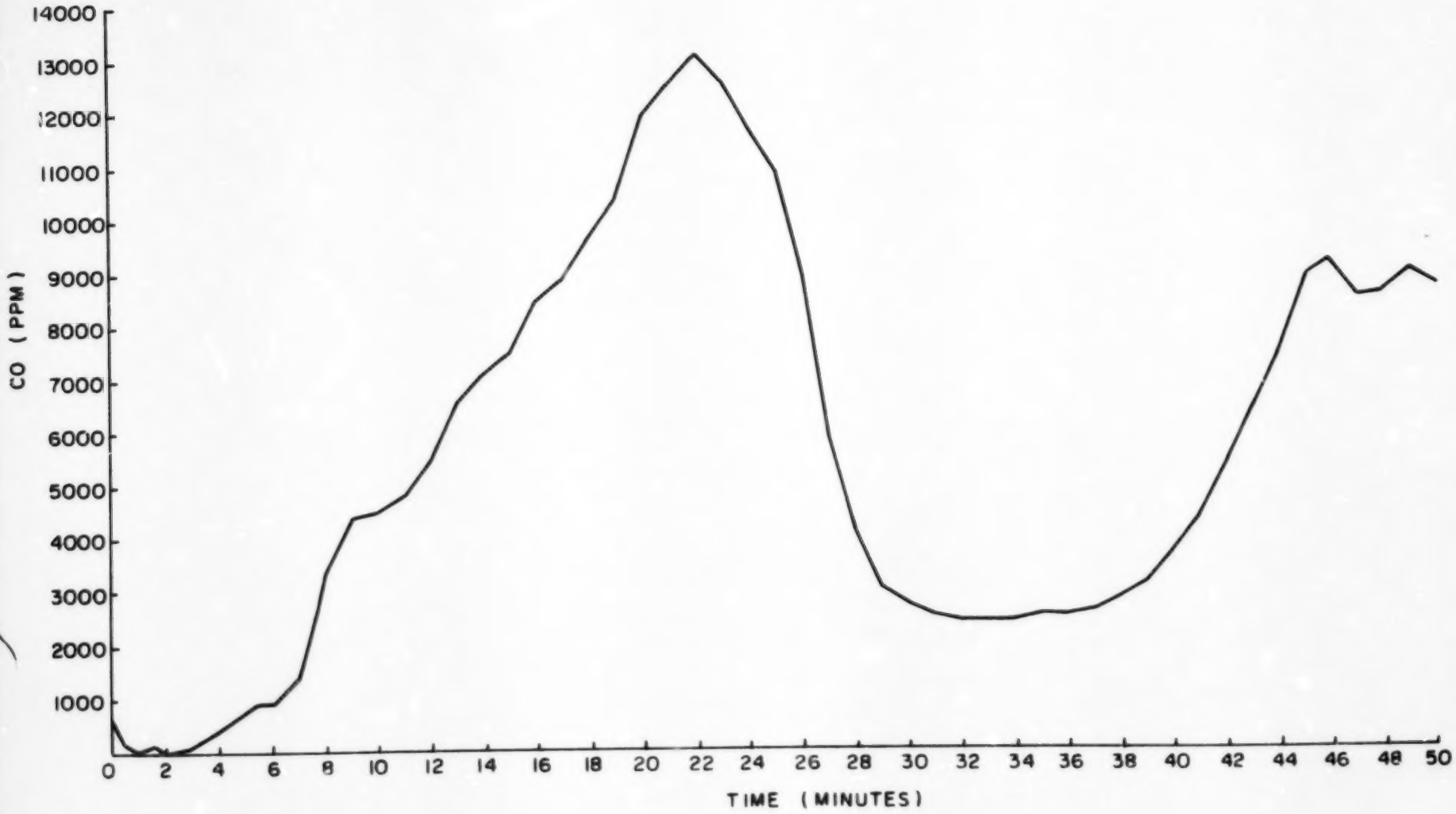

FIGURE 46 CARBON MONOXIDE CONCENTRATION vs TIME - BURNOFF No. 4.

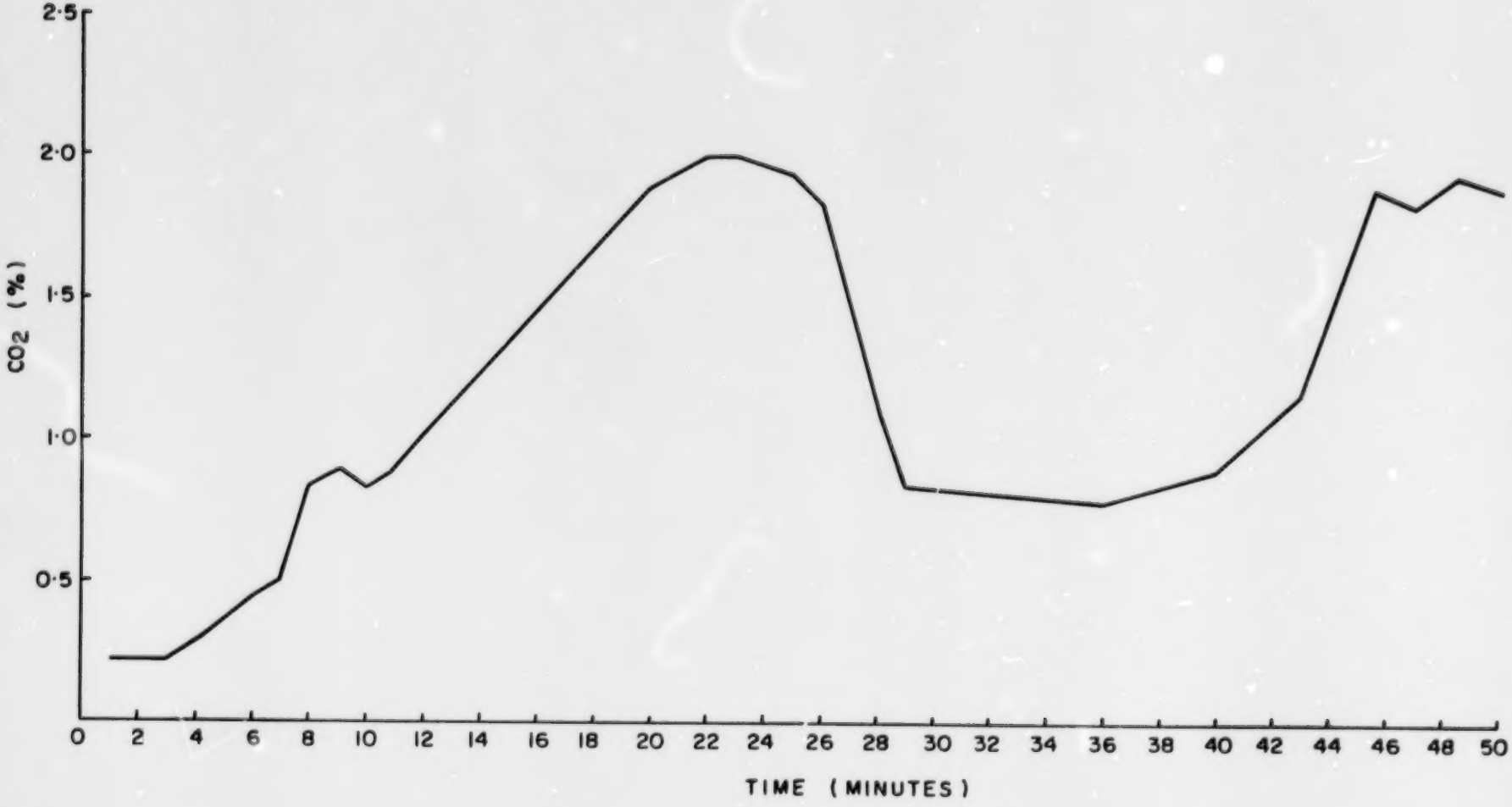

FIGURE 47 CARBON DIOXIDE CONCENTRATION vs TIME - BURNOFF No. 4.

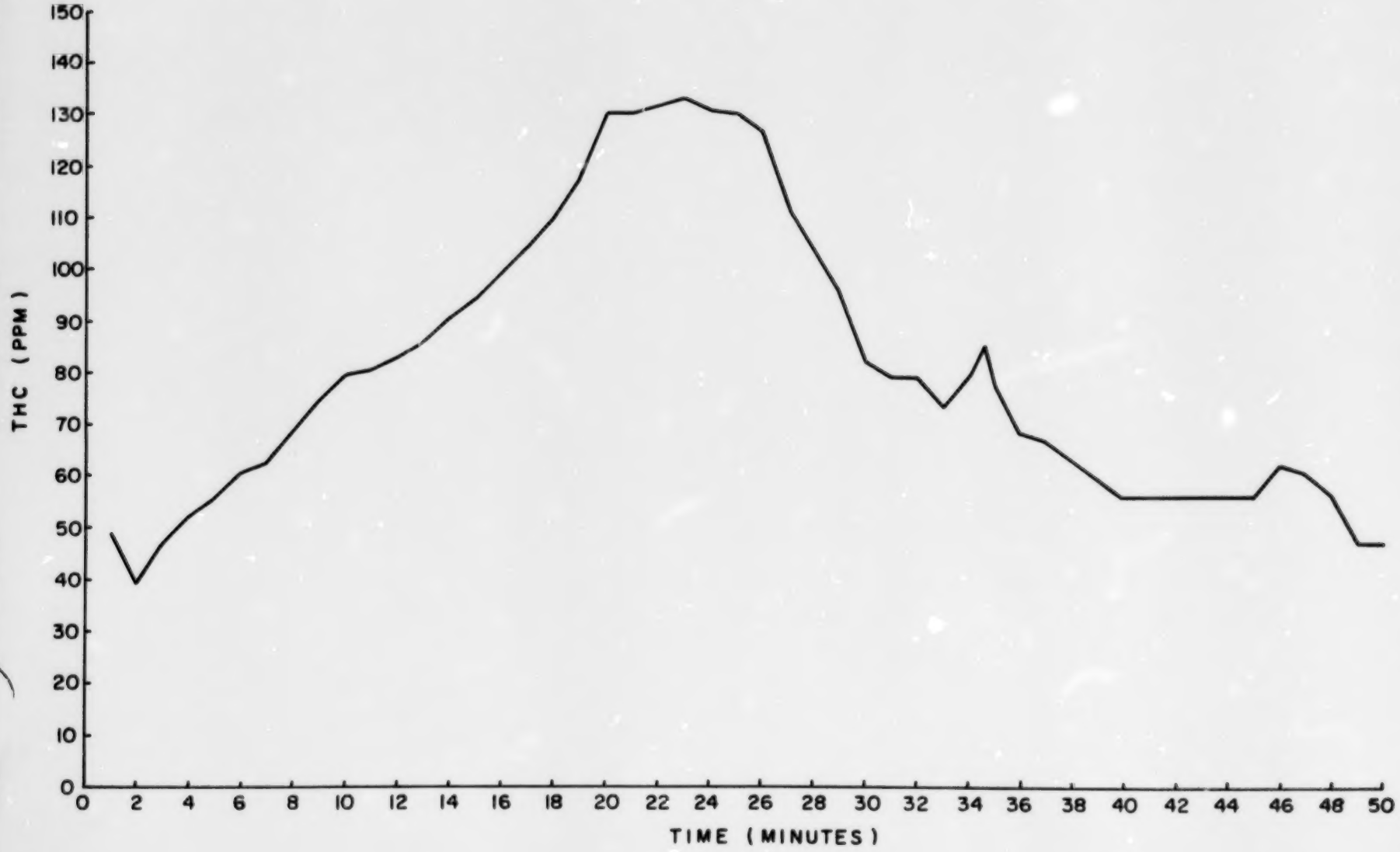

FIGURE 48 TOTAL HYDROCARBON CONCENTRATION vs TIME - BURNOFF No. 4.

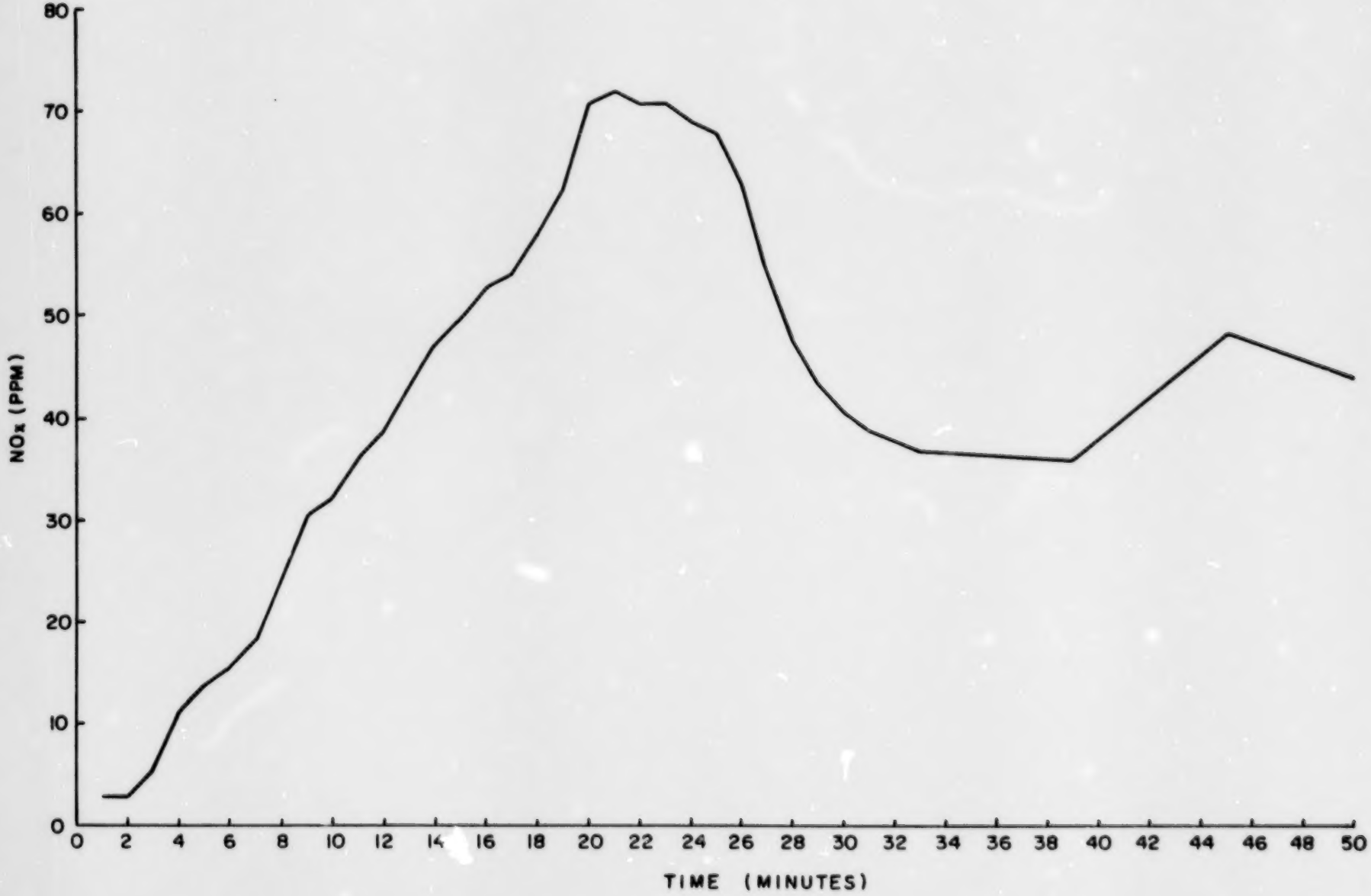

FIGURE 49 OXIDES OF NITROGEN CONCENTRATION vs TIME - BURNOFF No. 4.

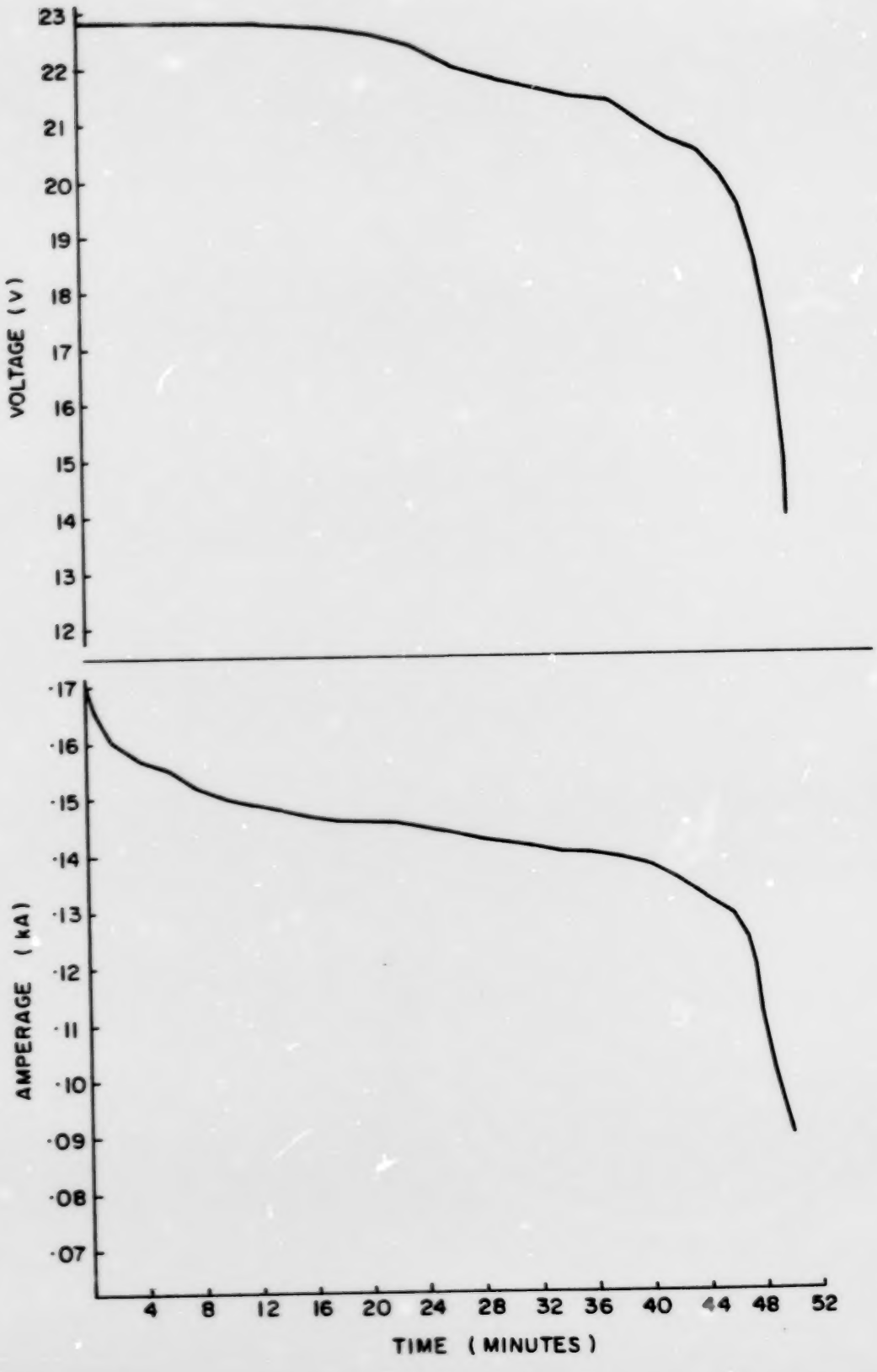

FIGURE 50 VOLTAGE AND CURRENT vs TIME - BURNOFF No.1.

APPENDIX

Gaseous Emission Concentration Profiles
For Burn Nos. 2 and 3

Figure 1: CO(PPM) VS TIME (MIN) BURN #2

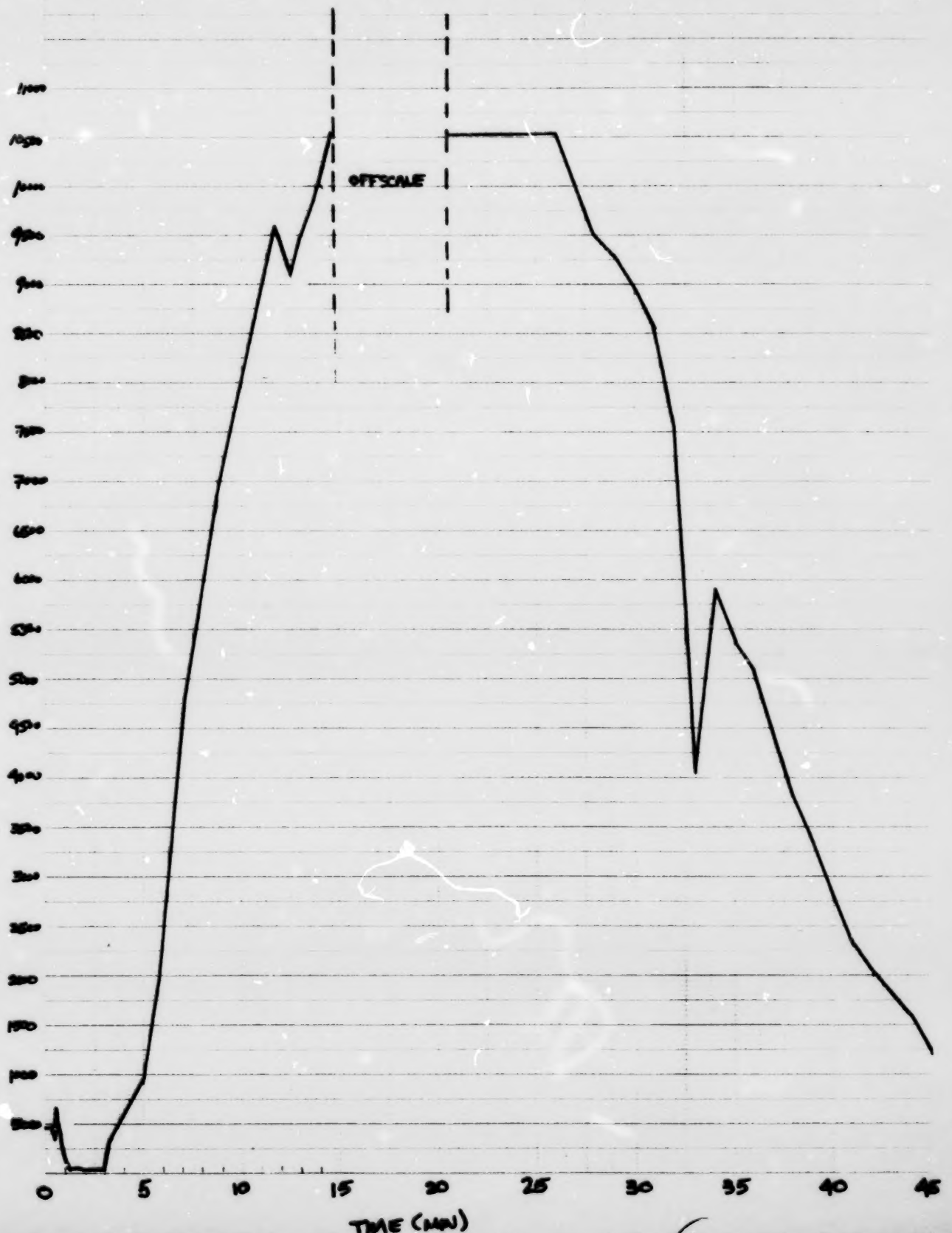

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Figure 2: Corning Filter Burnoff NO, NOx Test 2

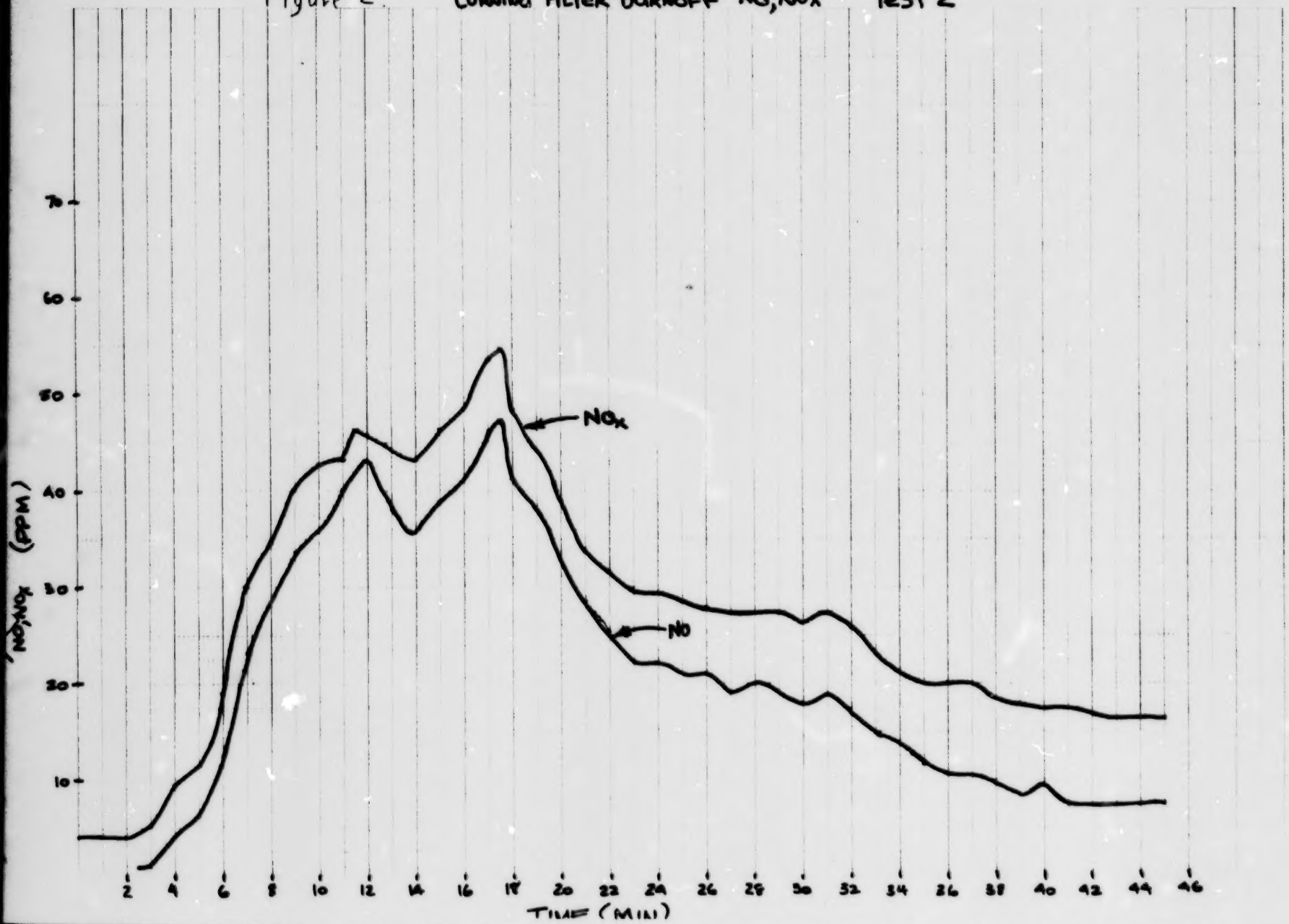

Figure 3: CORNING FILTER BURNOFF (CO_2) T.2. VS TIME (MIN.)

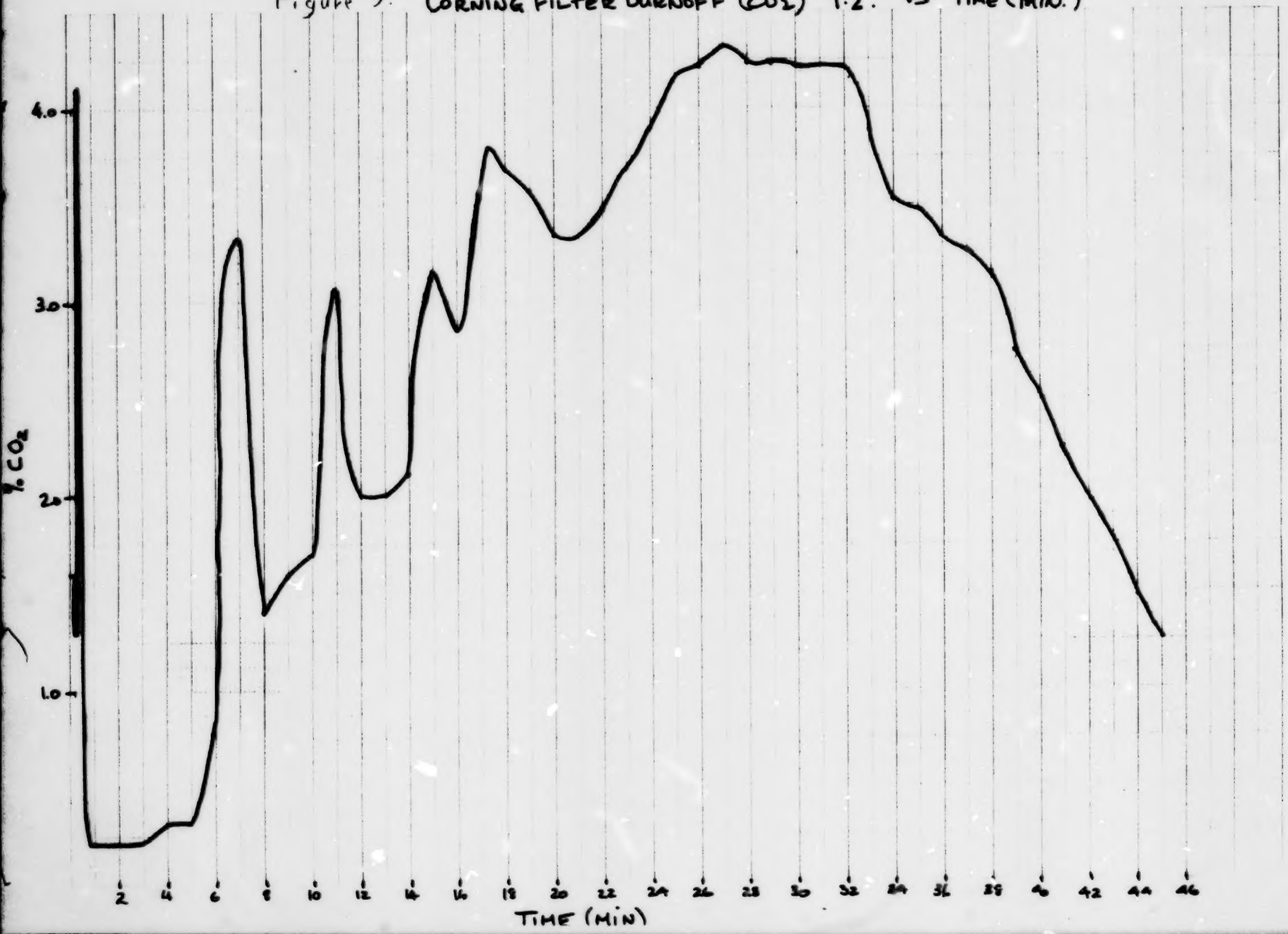

Figure 4: THC (PPM) VS TIME (MIN) BURN #2

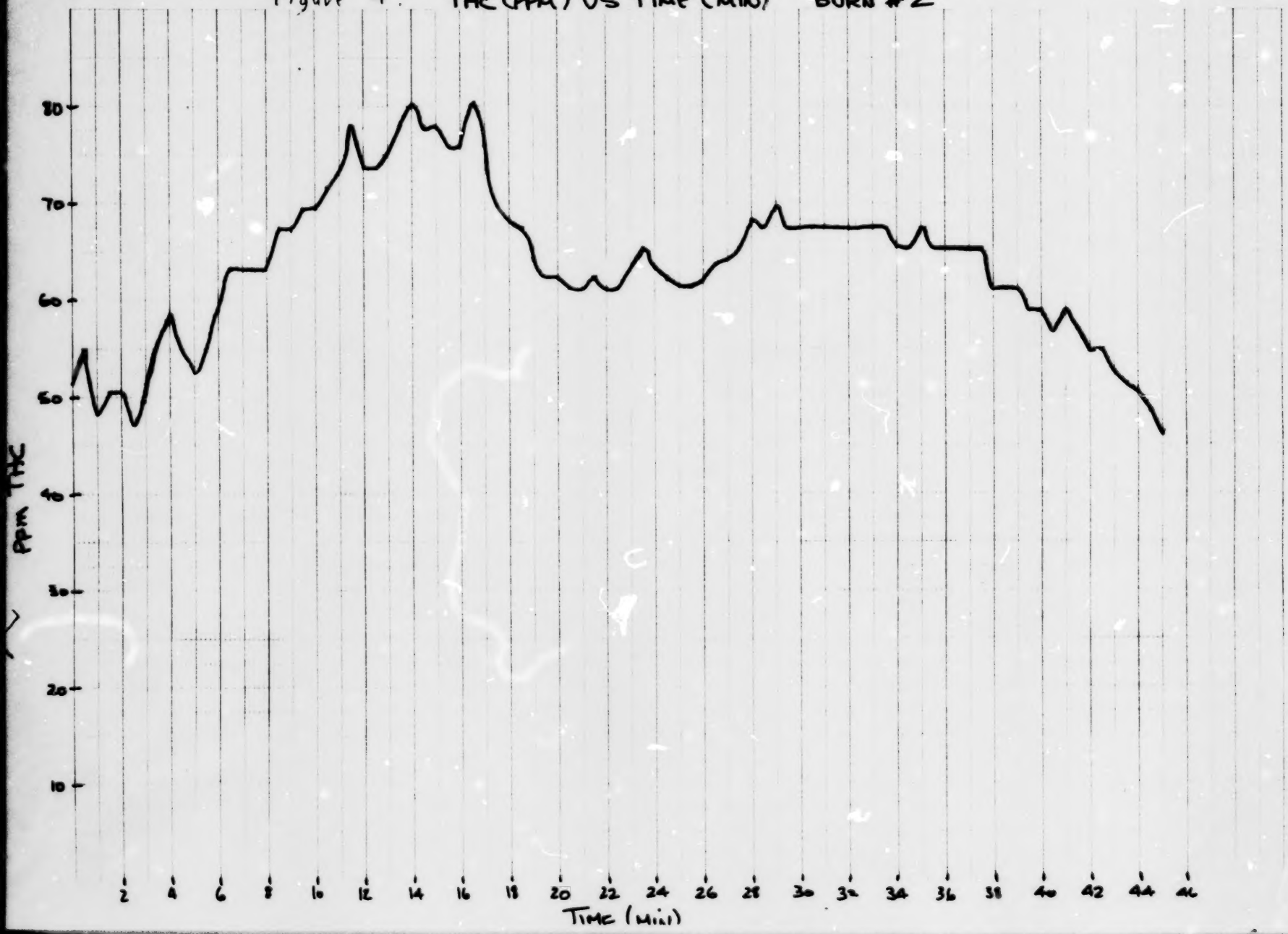

Figure 5: GRAPH OF ppm CO vs. TIME FOR BURN #3

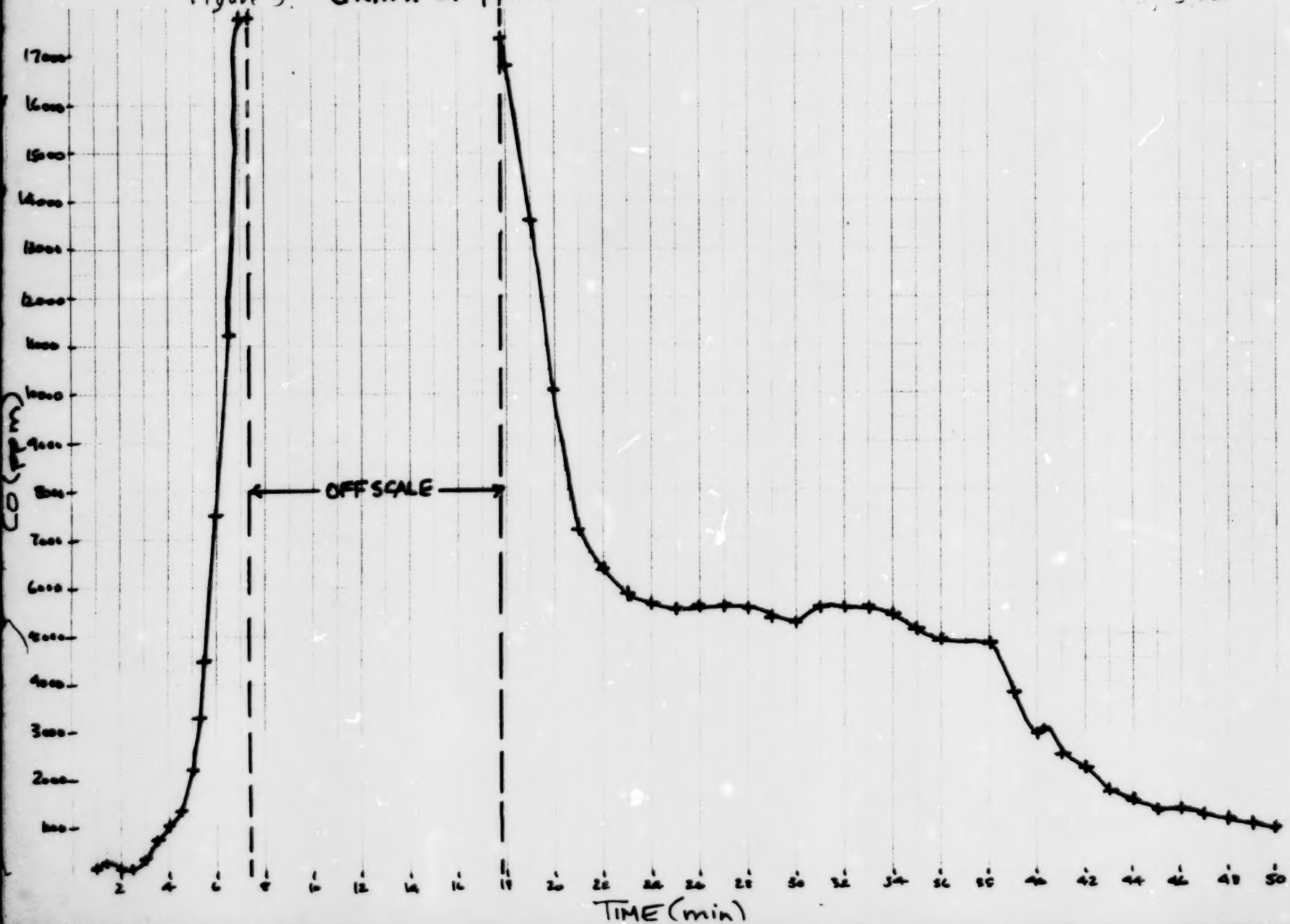

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Figure 6: GRAPH OF %CO_2 VS. TIME FOR BURN #3

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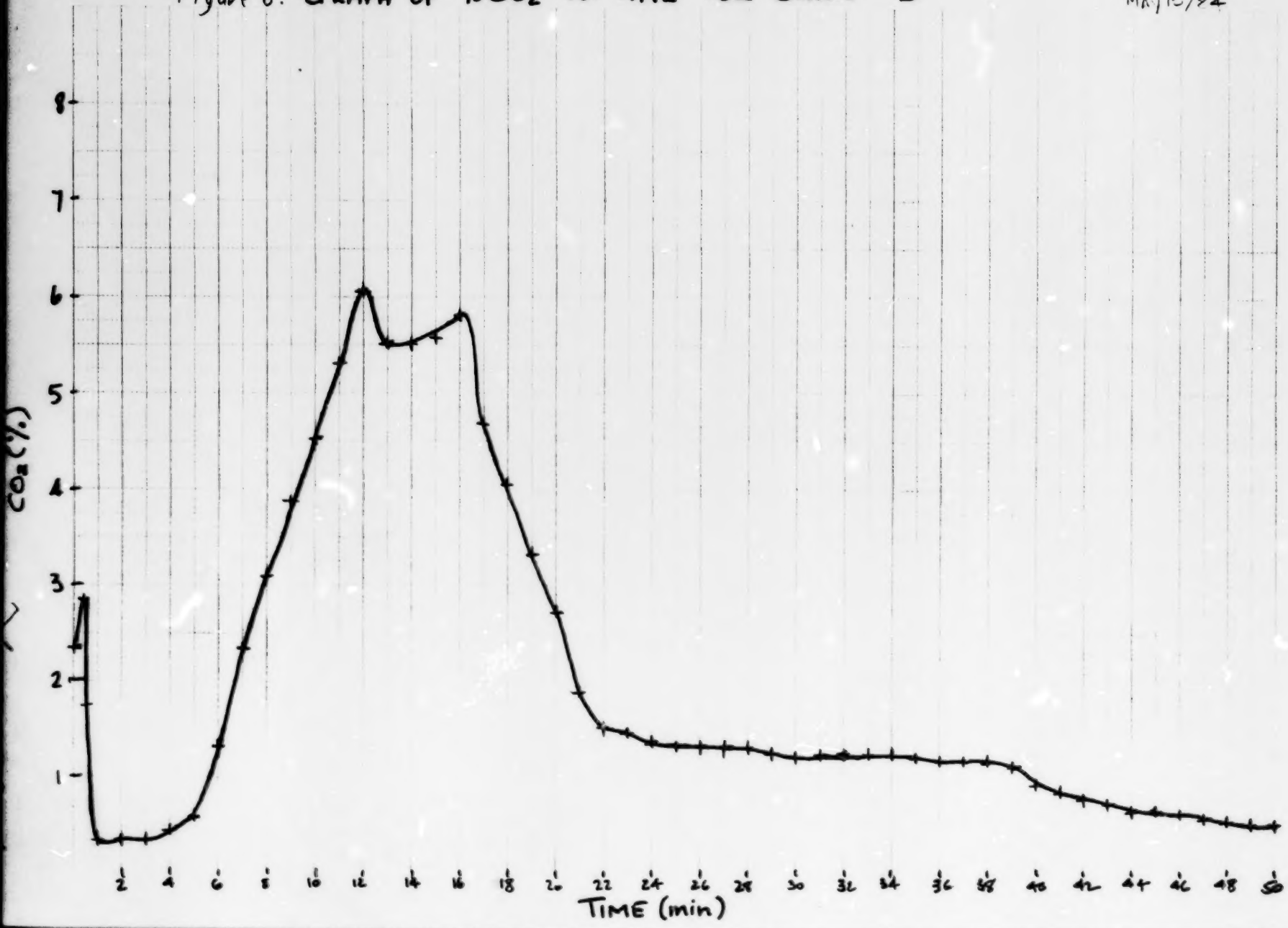


Figure 7: GRAPH OF ppm THC vs. TIME FOR BURN #3

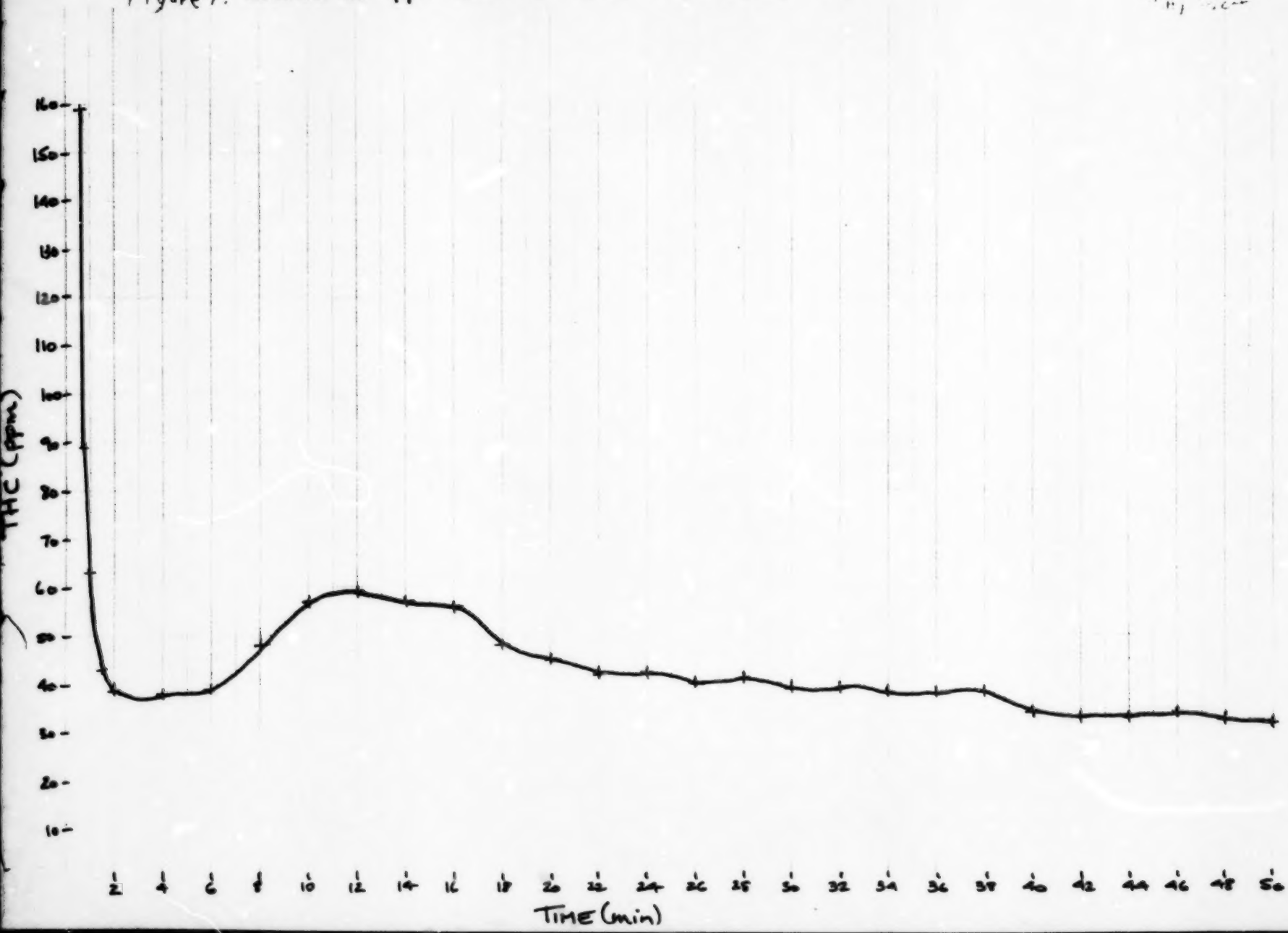
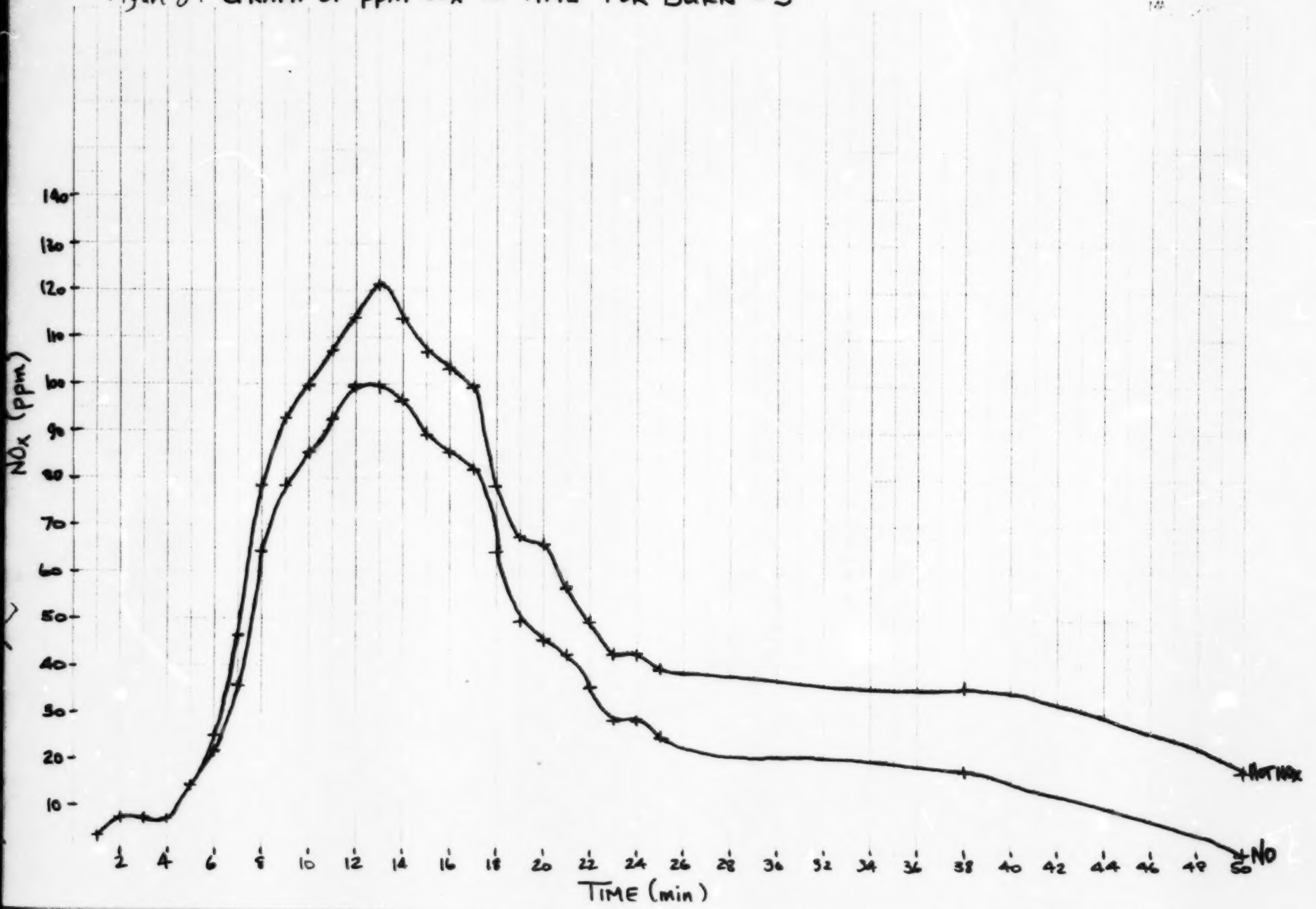


Figure 8: GRAPH OF ppm NO_x VS. TIME FOR BURN #3



ONTARIO**RESEARCH**
FOUNDATION

Energy

energy conservation programs and analyses, thermal insulation design and evaluation, waste heat recovery, building energy systems and monitoring, heat storage systems and materials, thermoelectric generation, combustion technology, burner development, heat transfer analysis, solar systems monitoring, National Solar Test Facility, solar technology, wind power, coal, lignite and oil sands processing, alternate fuel utilization, battery and fuel cell technology, peat processing and utilization, fenestration measurements, heat pump development and test facilities, residential heating systems, air to air heat exchange test facility, photovoltaic devices, . . .

Environment

ambient air quality assessment, environmental impact assessments, long-range transport of atmospheric pollutants, precipitation chemistry, particulate characterization studies, emission inventories, source sampling, odour emission and control, asbestos measurement and control, occupational health and safety studies, diesel emission control technology, air pollution control, pesticide residues, trace metal analysis, trace organic analysis, radionuclide analysis, mutagenic testing, noise and vibration analysis, radiation measurements, particulate identification and measurement, water surveys, water purification, industrial and municipal wastewater treatment, membrane separation techniques, wet oxidation, solid waste treatment and recovery, hazardous waste treatment and disposal, indoor air quality assessments, priority pollutant analysis, landfill technology, . . .

Materials

building materials, plastics, composites, metals, glass and ceramics, wood and wood composites, biomaterials, adhesives and printing inks, fibres, yarns, fabrics and geotextiles, leather, organic and inorganic chemicals, specification development, quality assurance, mechanical, chemical and thermal properties, test method development, failure analysis, fire and flammability, glass-metal seals, metal and alloy powders, metallography, materials characterization, materials characterization by optical and electron microscopy and X-ray microanalysis, photovoltaic materials, materials corrosion resource centre, corrosion properties and control, bacterial corrosion, coatings and sealants, rubber technology, X-ray analysis, cement and concrete, soils and aggregates, gypsum, body armour testing, footwear, paper-making materials, roofing and waterproofing, waste material stabilization and solidification, . . .

Products & Processes

clothing, footwear and industrial textile products, knitting technology, thin and thick film systems, microelectronics development, fibre optics, instrumentation, bioengineering, ultrasonic and fluid shear devices, microwave drying, transportation and equipment testing, mathematical stress and vibration analysis, product, equipment and machinery design & development, fuel emulsification, organic analysis and characterization, chemistry of foodstuffs, pulp and paper processes, ceramics processing, metallurgical process development, powder metal technology, packaging applications, technical and economic evaluations, industrial engineering applications, process control, enzyme analysis, electrical testing, radioactive surveys, industrial microbiology, biotechnology, technical and management skills development seminars, paper products, absorbent consumer products, detergent and cosmetic formulation, metal chemical analysis, flash hydropyrolysis of coal, electroplating, . . .

Resources

mineral processing, hydro and pyrometallurgical processing of ferrous and non-ferrous ores, coal evaluation, coal ash utilization and product development, asbestos processing and applications, non-metallic minerals/industrial minerals processing and utilization, uranium processing, forest utilization, utilization of forest and agricultural wastes, utilization of industrial, mining and domestic wastes, energy and chemicals from biomass, in-plant waste reduction, mineralogical services, mining and metallurgical waste disposal, . . .

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